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ADJUSTMENT AND TESTING OF RADIO EQUIPMENT

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The Russian Alphabet and Transliteration

А а	a	К к	k	Х х	kh
Б б	b	Л л	l	Ц ц	ts
В в	v	М м	m	Ч ч	ch
Г г	g	Н н	n	Ш ш	sh
Д д	d	О о	o	Щ щ	shch
Е е	e	П п	p	ъ	"
Ё ё	ë	Р р	r	ы	y
Ж ж	zh	С с	s	ь	'
З з	z	Т т	t	Э э	e
И и	i	У у	u	Ю ю	yu
Й й	y	Ф ф	f	Я я	ya

CONTENTS

CHAPTER 1

Adjusting and Testing Radioelectronic Equipment. General

1.1. BASIC DEFINITIONS

Radioelectronic equipment contains many parts, assemblies, and devices: chassis, mechanical controls, waveguide and coaxial lines, electronic valves, transistors, capacitors, chokes, transformers, etc. Parts, assemblies, and devices are manufactured within certain tolerances, i. e., the properties of similar components may differ within certain permissible limits. These differences may develop even in components manufactured at one and the same factory by the same manufacturing process, due to various random causes which cannot be fully eliminated. Thus, a fluctuation in the supply mains voltage causes a variation in the conditions of impregnating, drying, and annealing. Gradual wear of tools and equipment leads to a change in the dimensions of parts and this, in its turn, to a change in electrical parameters.

The more complex the radioelectronic equipment, i. e., the greater the number of components it includes, the greater the number of reasons for changes in its basic properties. The most important properties that characterize the operation and accuracy of a device are called its *parameters*. The maximum difference in parameters is known as *spread*.

In order to reduce the spread in parameters, it is necessary to check the materials and parts making up the equipment and to adhere strictly to the technological conditions.

Technological charts for manufacturing parts, assemblies, and devices envisage parameter-checking operations.

Checking is done either by examining the equipment or by testing it with various gauges and measuring instruments. Checking may be either passive or active. In passive check-

ing, good components are separated from rejects, while in active checking, the check results are analyzed to discover the cause of the defect and to introduce the appropriate changes into the manufacturing process. Parts, assemblies, devices or systems of devices are pronounced fit if their parameters are within the permissible limits.

The technical requirements to be met by the equipment are established by standards and specifications.

Most radioelectronic devices require adjustment, because immediately after assembly they do not meet the specifications. This is due to the fact that valves, semiconductor devices, resistors, and capacitors possess considerable spread in their parameters.

The technical operations which after assembly bring the parameters or characteristics of a circuit, unit, equipment, or system within the specified technical requirements are known as *adjustment* or *alignment*.

Adjustment is made with the aid of components, the parameters of which may be varied: variable capacitors, variable resistors, variable inductance coils, or by replacing individual components. During adjustment the operation of the equipment is checked and those faults are brought to light which were not discovered during examination after assembly and wiring of the circuit.

In adjustment, great significance is attached to the measurements of voltages and currents, the observation of oscillograms, etc. By analyzing the results of the measurements, the adjuster determines which component should be replaced or adjusted. Measurements are continued until the required results are obtained.

The adjusted equipment is tested. By *testing* of equipment is meant ascertaining whether it conforms to the specifications. Testing includes measurement of the parameters of the equipment and of its components under various (given) operating conditions, as well as throughout a certain time. By testing is meant the checking of the stability of the equipment operation under the effect of outside factors: climatic, mechanical, and electrical.

Tests can be divided into climatic, mechanical, and electrical. Their aim is to ascertain whether the equipment under test will operate normally with variations in the

supply mains voltage, temperature, humidity, and atmospheric pressure as well as being vibrated under the given operating conditions throughout a given period of time. The answer is supplied by testing a sufficient number of components of the given type, by measuring their parameters, i.e., it is necessary to carry out a set of checking and testing operations.

Under batch production conditions, checking and testing operations are carried out by the technical inspection departments. It is their duty to check materials, parts, and units arriving from the suppliers (incoming inspection), to check the quality of operations performed (process inspection), and to check the finished products (final inspection).

The head of the inspection department is personally responsible for the quality of the finished products. His duty is to forbid the release of the product if it does not meet the specifications, to supervise the work of the shop technical inspectors who are responsible for the quality of the checking operations performed in the shops, etc.

The head of the inspection department may also be in charge of laboratories intended for analyzing rejects and for avoiding them, as well as of laboratories for conducting so-called *sampling inspection*, which are also known as *standard-test laboratories*.

Sampling inspection signifies the testing of a part of the manufactured articles. These tests serve as a basis for pronouncing fit or unfit not only those articles that were tested but the whole batch in which the sampling took place.

100 per cent inspection of equipment against all items of the specifications, including requirements of stable operation under the effect of variable temperature, humidity, shaking, vibration, and other factors, is always based on the sampling, and in most cases the equipment tested against all items of specifications is no longer fit for service.

Alignment of radio equipment is carried out under comparatively favourable conditions, i.e., in heated rooms and, as a rule, in the absence of mechanical effects. But it is the duty of the adjuster to align the equipment so that it will operate stably under actual operating conditions: on aircraft, ships, motor, and other vehicles.

...he adjuster and the inspector must know what typical ...ts may be caused by various outside factors. For this it ...necessary to examine the operating conditions of radio ...uipment and the effect of climatic and mechanical factors ... its operation.

...2. OPERATING CONDITIONS OF RADIO EQUIPMENT

...Classification of Operating Conditions

By operating conditions are meant all the outside factors which significantly affect the operation of the equipment. Among such factors are temperature, humidity and pressure, vibration, impacts, etc.

Various components of the same equipment may operate under different conditions. For example, the body of a hermetically sealed device may be subjected to high humidity, while the components contained in it are under normal conditions of humidity; components located closer to powerful valves and power transformers are under conditions of higher temperatures; components mounted on shock-absorbers are subjected to weaker mechanical effects than the rest.

The specifications of radio equipment specify the conditions under which the equipment as a whole operates.

According to operating conditions equipment may be divided into three groups:

equipment operating under normal conditions;

equipment operating under natural climatic conditions on the ground;

equipment operating on board high-speed aircraft, rockets, etc.

By normal operating conditions is meant operation indoors, in heated rooms, in the absence of mechanical effects and pollution of the air with dust, vapours, gases, solutions of salts and acids, and microorganisms. The temperature in such rooms is maintained within 20±5°C, relative humidity, within 50-80 per cent, atmospheric pressure within 720-780 mm Hg, and care is taken that there are n... sharp fluctuations in temperature, humidity, and pressur... Normal conditions of operation are typical for radio-broa... casting and television equipment, stationary communi...

tion transmitters and receivers, factory intercom systems and similar equipment. Radio equipment is adjusted and some types of it are tested under normal conditions.

Equipment operating under on-the-ground climatic conditions, depending on its purpose and expected conditions of operation, is divided into stationary, motor, tank, ship, as well as that intended for operation in deserts, mountainous regions, tropical climates, and other conditions.

Various types of airborne and rocket-borne equipment are subjected to significantly different conditions.

Not only climatic but also mechanical factors exert influence on mobile equipment. It may vibrate and experience blows. In case of sharp changes in velocity, both in magnitude and direction, considerable linear loads develop.

But this does not mean that all the components of a radioelectronic system must be designed for the conditions under which the system as a whole operates. Thus, by housing some components in hermetically sealed cases, one can preclude the action of reduced atmospheric pressure, sand and dust on them, and by employing shock-absorption for a unit, it is possible to make the effect of mechanical loads weaker, etc.

The application of protective means against the effect of the ambient medium and mechanical overloads increases the equipment cost, size, and weight. Therefore, protective means should be used only in case of necessity.

Transportation and Storage Conditions

In addition to the operating conditions the capacity of equipment to operate is significantly affected by the conditions of transportation and storage. When equipment is transported, loaded, and unloaded, mechanical loads develop which may render the equipment inoperative. Equipment which is not designed for such loads during service is packed into boxes with shock-absorption to protect it from mechanical damage during transportation. In such cases, equipment is tested in its packing for the effect of mechanical overloads during transportation.

During prolonged storage of equipment in unheated premises, its efficiency may be disturbed due to changes in

temperature, humidity, and other climatic factors. In different climatic zones of the earth and at different seasons this effect may be more or less pronounced.

Climatic Conditions

Climatic conditions vary greatly in different zones of the earth. They may vary greatly throughout the day and depending on the season, with periodic variation in solar activity, etc.

This variety of climatic conditions may be reduced to four types:

dry heat, i.e., high temperature and low humidity;

tropical humidity, i.e., high temperature and high air humidity;

cold;

moderate climate.

Under this classification, the parameters determining the climatic conditions are temperature and humidity.

The degree of air humidity is characterized by the relative humidity.

The *absolute humidity*, i.e., the weight content of water in one cubic metre of air, does not characterize sufficiently the effect of humidity on equipment. At a given absolute humidity the precipitation of moisture on surfaces and its absorption by hygroscopic materials depend on the ambient temperature. At lower temperatures dew precipitates at a lower absolute humidity. At a given absolute humidity and a certain temperature, known as the dew point, the air becomes saturated with water vapour and further lowering of the temperature brings about the condensation of the water vapour and the formation of mist.

The ratio of the absolute air humidity at a given temperature to the absolute humidity at the dew point is called the *relative humidity*. The dew point corresponds to a humidity of 100 per cent.

The effect of a high humidity is especially pronounced at humidities of 90 per cent and higher.

For determining the operating conditions of equipment in high-altitude regions and in the upper layers of the atmosphere, it is necessary to take into account the effect of reduced atmospheric pressure and of solar radiation.

Effect of Mechanical Loads on Equipment

The mechanical loads experienced by equipment during vibration and impacts are characterized by frequency and acceleration.

Frequency is the number of oscillations (in vibration) or the number of impacts per second. Frequency is measured in hertzes (Hz).

The amplitude of acceleration in vibration or the maximum acceleration during an impact is conventionally expressed in units of acceleration of the force of gravity, i.e., the number indicating how much greater the maximum acceleration is than the acceleration of the force of gravity

$$j = \frac{a_m}{g}$$

where a=amplitude of acceleration
g=acceleration of the force of gravity equal to 9.81 m/s^2
j=load factor showing how many times the amplitude of acceleration exceeds the acceleration of the force of gravity

Equipment operating under normal conditions is subjected to mechanical overloads mainly during transportation. During loading, unloading, and transportation, the equipment may be subjected to mechanical effects having various frequencies and accelerations. Thus, during loading and unloading, impacts are possible which are conventionally characterized by the height of a free fall to the ground. The maximum free-fall value for equipment designed to be transported is 500-700 mm.

When equipment is transported by various means of transportation, the following parameters of mechanical effects are typical:

motor transport: vibration frequency f=1 to 3 hertzes, acceleration up to 2 g and simultaneously f=15 to 40 hertzes, acceleration 1 g;

railways: vibration frequency up to 100 hertzes, acceleration up to 1.5 g. When trains are shunted, the impact acceleration reaches 20 g;

air transportation: vibration frequency up to 400 hertzes, acceleration up to 7 g.

Mechanical loads may be of a very complex nature and applied in different directions. They may vary in different parts of the vehicle in which the radioelectronic equipment is installed. Let us examine this taking as an example the equipment installed in ships, aircraft, and rockets.

Shipborne equipment. The impacts experienced by the equipment depend on its weight and its position on the ship. Great mechanical overloads develop during rolling and pitching. Considerable overloads may also develop when the ship is manoeuvring; in different points of the ship not only different overloads develop but also different absorption of the impacts occurs. Vibration is produced by the screws and the engine work. The main vibration, i.e., that of the hull, is produced by the work of the screws. In most ships vibration of the hull is greatest at the bow and the stern and decreases towards midship.

Equipment installed in aircraft and rockets. During takeoff (launching), landing, and changes in the flight direction and speed of the aircraft or rocket, the equipment is subjected to acceleration in many directions. In addition, during takeoff and landing, especially in cases of emergency, powerful linear overloads, rapid acceleration, sharp braking as well as impacts and vibration are possible. Just as on board ship, the work of the engines produces vibration, the amplitude and frequency of which depend on the position of the equipment, its weight, and the methods of securing it to the body of the aircraft or rocket.

1.3. EFFECT OF CLIMATIC AND MECHANICAL FACTORS ON OPERATION OF RADIO EQUIPMENT

Climatic factors. The action of high and low temperatures may cause the deterioration of certain materials and impermissible changes in their properties. Variation of temperature brings about changes in the physical and chemical properties of materials, their volume, hardness and resilience, as well as in their electrical and magnetic properties. This causes a change in the capacitance of capacitors, the inductance of coils, the value of resistors, the parameters of valves and semiconductor devices, the magnetic properties of magnetodielectrics, etc. Certain types of

insulating materials, for example, rubber, under the influence of high and low temperatures become brittle, crack, and lose their insulating properties. The deterioration of coatings and variation in the properties of impregnating materials are possible, which causes breakdown through the thickness or across the surface of dielectrics.

At low temperatures, certain types of electrolytic capacitors fail to operate, wax and certain protective compounds harden and crack, storage batteries discharge in the case of insufficient density of the electrolyte. The thickening of lubricants at low temperatures may cause jamming of the moving parts of mechanisms.

Gaps or local stress may develop at joints between materials with different temperature coefficients of linear expansion. Violation of contacts in connectors is possible because metal and plastics possess different temperature coefficients of expansion; relay contacts are often found to be stuck, hermetical sealing may be violated, and other damage occurs due to changes in temperature.

High air humidity causes a decrease in the surface resistance of dielectrics and the volumetric resistance of hygroscopic materials. Water vapour settling on the surfaces of dielectrics and mixing with dirt forms a conducting film. The surface resistance of the dielectric decreases and it may shunt the leakage resistance of a valve or any other high-ohm resistance. This may occur, for example, when high-ohm resistors are mounted on pertinax panels with lugs and low-quality lacquer coating of the panel surface. In addition, breakdown may occur across the panel surface between the lugs.

Atmospheric moisture contains, in addition to water vapour, solutions of salts and acids. Settling on the surface of metal, the moisture forms an electrolyte film which reacts chemically with the metal. There follows rapid destruction of the surface of the metal, i.e., corrosion. Corrosion decreases the mechanical strength of metal, violates contacts, and causes breakage of wires. At places where metals come into contact, a galvanic pair interspaced by the electrolyte film develops, and corrosion proceeds especially rapidly.

If the equipment is subjected to salty spray or if, during

operation, it is submerged in salty water, for instance, sea water, the danger of corrosion increases, especially in the places where different metals come into contact.

In warm, moist, and dark places where air is stagnant, favourable conditions develop for the formation of mould. Mould fungi occur in large amounts in the soil. On getting into the equipment together with dust, they multiply rapidly forming mould. Feeding on various insulating materials included in the equipment, the fungi destroy them. Mould contains much moisture which facilitates corrosion of the metal.

Dust may contain not only mould fungi but also dissoluble salts. On getting into the equipment and absorbing moisture from the air, such dust becomes a conductor, reducing the surface resistance of dielectrics and increasing the corrosion of metal. Indissoluble particles of dust and sand accelerate the wear of mechanisms and may violate contacts in switches and relays.

Reduced atmospheric pressure causes a reduction in the heat conductivity of the air and in its electrical penetrability. In its turn, the reduction in the heat conductivity of the air worsens heat removal, and the temperature of the equipment increases. Variation in electrical penetrability changes the capacitance of air capacitors and coil capacitances. In addition, with a reduction in atmospheric pressure, the electrical strength of air decreases, increasing the danger of breakdown across air gaps.

Ionization of the air by sun rays increases still more the danger of breakdown. Intensive irradiation by sun rays raises the temperature of the equipment. In addition, sunlight decomposes lacquer and paint coatings, certain plastics, and textiles.

The capacity of equipment to operate is greatly affected by storage conditions. In damp, warm, and dark places favourable conditions develop for the formation of mould. Storage in the frost brings about changes in the properties of certain dielectrics.

Especially harmful are sharp variations in temperature which may be due to diurnal variations, transfer of the equipment from a cold to a warm room and vice versa, due to periodic heating of the place of storage, etc. For example,

if equipment installed in a motor vehicle was out in the frost for a long time and then the vehicle body was heated, moisture will appear in the equipment, which may be the cause of breakdown across the surface of dielectrics.

Mechanical factors. Mechanical factors may cause violation of the mechanical strength both of components of the equipment and of their fastenings and connections: poorly soldered joints may come apart; contacts become violated; with insufficient shock-absorption the electrodes of valves may short-circuit; barely noticeable cracks on the surface of vitrified resistors may lead to chipping off of the protective coating.

The absence or poor quality of fixing devices (lock washers, lock nuts, cotter pins, fixing dope, etc.) may cause working loose of screws. Mechanical factors may cause violation of the contacts of relays and switches, spontaneous displacement of potentiometer sliders, breakage of wrongly bent leads of radio components, and the short-circuiting of wires with damaged insulation, as well as of bare wires, if the hookups are not sufficiently rigid.

In addition, brittle materials may become cracked or chipped, ceramic may chip off, especially at the places where ceramic parts are fastened. Poor-quality coatings may peel off or crack.

Especially dangerous is the phenomenon of resonance, i.e., when the inherent frequency of mechanical oscillation of components or assemblies coincides with the vibration excitation frequency. In the case of mechanical resonance of components or assemblies violation of the equipment efficiency may develop. For example, the vibration of hookup wires or the vanes of a variable capacitor in the oscillator circuit may cause the occurrence of parasitic frequency modulation, and during impacts, brief frequency departure. For detecting resonance the equipment is tested within the range of vibration frequencies.

The mechanical strength of equipment depends to a great extent on the method of mounting resistors, capacitors, etc. When small components vibrate at their resonance frequency, there may occur breaks at soldered joints or in hermetical sealing, short-circuits between leads, and other damage. The resonance frequency of suspended components

depends on the length of their leads. For example, components with leads 25 mm long and a diameter of 0.6-1 mm have a resonance frequency of 1,000-1,500 hertzes. By shortening the leads of suspended components, it is possible to shift their resonance frequency beyond the range of vibration frequencies of the equipment. The vibration of variable capacitor vanes at audio frequencies produces the microphone effect. In the case of audio frequency transformers and chokes resonance may cause breakage of their fastenings (bolts, brackets, pins).

Impacts usually affect bulky components: audio frequency transformers and chokes, large capacitors, as well as radio valves and ceramic parts (shafts, panels, etc.). Impacts may cause large components to break and ceramic and other brittle components to crack.

Adjustment and Testing Requirements

Having considered the effect of climatic and mechanical factors on the operation of radio equipment, one can come to the conclusion that equipment, which under normal conditions fulfils its functions well, may fail under actual operating conditions due to changes in the electrical properties of its components or to mechanical damage. In addition, there occurs a gradual change in the electrical properties of the components, which is known as aging.

For small variations in parameters not to cause failure, equipment must be adjusted so as to retain operability with considerable variation in parameters. Critical operating conditions of components must be excluded and adjustment made so that the departure of the adjusted parameter will be well within the limits permitted by the specifications.

When making any changes in the circuit, the adjuster should be very careful not to damage the insulation of wires, not to short-circuit the contacts of switches or relays, and not to cause any mechanical damage. On completing adjustment, the components being adjusted (potentiometers, trimmers, etc.) should be fixed so that they remain in position during mechanical loads.

If during the process of adjustment components are tem-

porarily disconnected or replaced, it is necessary to secure these components mechanically according to all the requirements of installation.

Adjustment often brings to light weak points of the design: bad hookup, insufficient insulation, critical operating conditions of certain components, etc. The adjuster must strive constantly to improve the quality of the equipment being adjusted, this being especially important when adjusting experimental samples.

It is desirable that radio equipment be tested under conditions close to the actual operating conditions. For this purpose, use is made of special installations which simulate various climatic, mechanical, and electrical conditions of operation. Certain testing installations are also used during adjustment.

Testing also brings to light shortcomings in design and manufacturing process, the elimination of which will help improve the quality of the equipment.

1.4. CLASSIFICATION OF TESTS

Radioelectronic equipment is tested during both its designing and its production. Tests made during designing are known as *preliminary tests*. Preliminary tests are subdivided into *bench* and *field* tests.

Bench tests are conducted at the place of manufacture of the equipment in specially equipped laboratories for all the parameters provided for by the specifications. In bench tests it is not always possible to simulate all the conditions of operation. In such cases field tests are carried out, i.e., tests under the actual conditions of operation of the equipment: in aircraft, ships, motor vehicles, etc.

Even thorough evolvement of the design and the manufacturing process of equipment does not exclude testing in both batch and mass production. This is due to the fact that there exist many unaccountable factors: the quality of primary materials, the condition of tools and equipment, the level of skill of the workers, the culture of production, and many others. One batch of materials or components received from the suppliers may differ from another batch, equipment and tools may wear down, a worker may violate

manufacturing process. The sooner such defects are discovered, the less will be the loss. That is why the system of inspection in batch and mass production provides not only for testing the ready product (final inspection) but also for inspection of various operations (process inspection) and checking the materials and components received from the suppliers (incoming inspection).

Incoming inspection set up directly in warehouses, where materials are stored and sets of components made up, or in special laboratories may vary in volume and nature. In some cases it is sufficient to check the documents and to examine the goods to see that no mistakes have been made during packing nor any damage has occurred during transportation and storage. In other cases it is necessary to make sample checks of the basic parameters.

Process inspection ensures timely detection of mistakes made by workers, the wear of tools, violation of normal operation of equipment, and many other causes of defects.

Final inspection includes acceptance and periodic (check) tests.

Acceptance tests are made by the inspection department to check each manufactured equipment in basic parameters. The results of acceptance tests are entered in a certificate that is delivered to the User together with the equipment.

In batch production a certain part of each batch of equipment is subjected to *check* (standard) *tests*, by which is meant checking of the equipment against all the requirements of the specifications, including testing under adverse climatic and mechanical conditions. In mass production such tests are known as *periodic* because they are repeated after definite intervals of time.

All types of tests include:

external examination for checking whether the equipment corresponds to the assembly drawings and the wiring diagram, and whether the assembly and hookup requirements have been met (in addition to the instructions contained in the wiring diagram and the assembly drawing, the general requirements for hookup-assembly operations specified by the corresponding standards should also be met);

checking the operation of the equipment under normal

conditions (the requirements for measuring and testing equipment and the procedure of checking the parameters of the equipment are set by standards and specifications).

Periodic and check testing includes checking the operation of the equipment under various climatic, mechanical, and electrical conditions, the conditions and order of the tests being set by standards and specifications.

Climatic tests are those in which the ability of the equipment to fulfil its functions is tested under various temperature, humidity, atmospheric pressure, and other climatic conditions.

Mechanical tests are those in which vibration, impacts, and linear acceleration factors are introduced.

Electrical tests include checking the effect of variations in supply mains voltage on the equipment, as well as checking the resistance and electrical strength of individual circuits.

1.5. CLIMATIC TESTS

Climatic tests are carried out according to a programme compiled on the basis of the specifications and standards, which determines the order, the conditions, and the time of the tests.

For each type of test, the programme specifies the values of the climatic factors: temperature, humidity, atmospheric pressure and their duration; it also sets the time when the various parameters should be measured or the operation of the equipment checked.

Types and Sequence of Climatic Tests

The programme of climatic tests is compiled so as to reproduce as fully as possible the most adverse conditions of operation. It should be borne in mind that the effect of climatic factors is determined not only by the absolute values of temperature, humidity, and pressure but also by the rate at which they change. In view of the complexity of the task and the high cost of equipment designed for simultaneously varying several climatic factors, separate tests are often carried out. The equipment is subjected to the effect

of separate climatic factors in turn: temperature, humidity, pressure, solar radiation, microorganisms (mould fungi), dust and sand, sea mist.

Thus in climatic tests the equipment is checked for:

resistance to heat at a temperature from +50 to +65°C during 4-10 hours;

resistance to cold at a temperature from —10 to —60°C during 4-6 hours;

resistance to moisture under conditions of tropical humidity during 48-96 hours;

resistance to spray during 2 hours;

resistance to moisture during 1 hour;

resistance to fungi, i.e., protection against the destructive effect of microorganisms during a prolonged time (30 days), at a temperature of +30°C, and a relative humidity of 98 per cent in a darkened chamber;

altitude at a reduced atmospheric pressure during 30 minutes;

resistance to the effect of hoarfrost and dew during 2 hours;

protection against dust during 1 hour;

protection against the effect of solar radiation;

protection against the effect of sea mist.

Of great significance is the order in which the tests are made. Climatic tests are conducted, as a rule, after mechanical tests, since the appearance of cracks and gaps after mechanical overloads accelerates the destructive effect of climatic factors. The effect of various climatic factors depends on the order in which climatic tests are carried out.

Let us examine three types of separate tests: for resistance to heat (H), for resistance to moisture (M) and for resistance to frost (F). The following test sequences are possible: H—M—F; H—F—M; M—H—F; M—F—H; F—M—H; F—H—M.

The most severe sequence is H—M—F. Under the action of high temperature, insulation can absorb moisture better. With subsequent testing for resistance to moisture the insulation absorbs moisture and when subjected to low temperature, the moisture expands, destroying the insulation.

Before each type of test and after it has been conducted, the equipment is checked in operation. In cases provided

for by the specifications, the parameters of the equipment are measured during the test and compared to the permissible values. For this the appropriate testing installations (chambers) have hermetical leads for supplying power to the equipment under test and connecting the measuring and testing instruments.

If checking of the parameters of the equipment during tests in the chamber is not stipulated, this is done either immediately after removing the equipment from the chamber or after keeping it for a certain time under normal conditions. The time for keeping the equipment under normal conditions is stated in the specifications and must be strictly observed.

Climatic tests are carried out in special installations. Installations for separate tests (heat, cold, moisture, etc. chambers) are simpler and cheaper, but they cannot be used for ascertaining the simultaneous effect of several climatic factors on radio equipment. Combination chambers are being ever more widely used. Especially widely used are combination chambers of heat and moisture, which make it possible to simulate conditions of tropical humidity; cold and pressure chambers for simulating the conditions of the upper layers of the atmosphere; and more complex chambers of heat, cold, and pressure.

Let us examine the operation of installations for climatic testing.

Heat chamber. The chamber is designed for testing the equipment under conditions of dry heat. The useful volume of the chamber should be sufficient for accommodating the equipment under test. The given temperature must be maintained for a long time, and the difference in temperature in different parts of the chamber's working volume should be insignificant.

Heat chambers are cabinets with double walls and a double bottom. The heater is housed in the double bottom. The diagram of a heat chamber is shown in Fig. 1. The warm air, heated by the heater, is sucked by the fan into the inner volume of the chamber and then passes on between the walls. Circulation of the air ensures its mixing and maintains the same temperature at all points in the chamber. The supply sources and the measuring instruments are

connected to the test equipment via insulated leads. For automatically controlling the temperature in the chamber use is made of regulators with heat-sensitive elements which switch the heater on, when the temperature in the chamber falls, and switch it off, when the temperature in the chamber exceeds the given value.

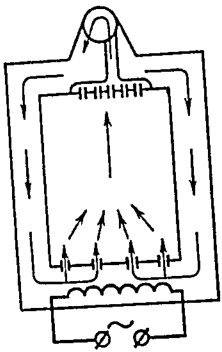

Fig. 1. Diagram of heat chamber

Cold chamber. Most often two types of cold chambers are used: with direct and indirect cooling.

Chambers with direct cooling have double walls, the space between which is filled with heat-insulating material, for example, asbestos or glass wool. The air in the chamber is cooled with dry ice, liquid oxygen, or nitrogen. The cooling agent is introduced directly into the chamber.

Such chambers are very simple in design but have a number of shortcomings: the temperature in them is practically uncontrollable; the introduction of certain cooling agents, especially oxygen, is dangerous, because, when the equipment is switched on, the appearance of sparks or breakdown of the dielectric is possible, which may cause a fire.

Considerably superior are chambers with indirect cooling, in which heat is absorbed by expanding gases. A simplified diagram of a chamber is shown in Fig. 2. The installation includes a closed circuit in which freon gas circulates. From condenser *1* the liquid freon under high pressure is injected into evaporator *2*, where it expands and evaporates, absorbing heat and cooling the working space of the chamber. The freon vapours are sucked out of the evaporator by low-pressure compressor *3* and

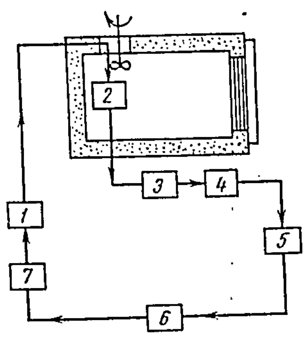

Fig. 2. Diagram of cold chamber with indirect cooling

pumped into cooler *4* in which the gas is liquified and cooled. From cooler *4* the freon is sucked into medium-pressure compressor *5* and fed to cooler *6*.

High-pressure compressor *7* operates in a similar way, pumping the liquified gas into condenser *1*. A fan is provided for stirring the air in the working volume of the chamber. The compressors and the accessories are arranged separately and connected to the chamber by tubes covered with heat insulation.

To supply the equipment under test and to connect the measuring and testing instrument, the chamber is designed with insulated leads. The temperature in the cold chamber is regulated automatically in a way similar to that of the heat chamber.

Heat and moisture chamber. The degree to which air humidity affects the operation of equipment is determined not only by the amount of vapour contained in a unity of air but also by the temperature. That is why modern moisture chambers include a system for heating the air. The diagram of a heat and moisture chamber is shown in Fig. 3.

Box double walls *1* contain heat-insulating material *2*. Between the chamber first wall and partition *7* is arranged heater *3*. Centrifugal pump *8* forces air to circulate through the layer of water in humidifier *9* and the working space of the chamber. Contact thermometer *10* is included in the circuit for automatically controlling the temperature of the water in the humidifier. The same circuit includes humidifier heater *11*. The degree of humidity in the chamber can be controlled by switching the centrifugal pump on and off. The air in the chamber is circulated by fan *6*. Leads *4* serve for connecting the power supply and the measuring instruments.

The humidity in the chamber is measured with psychrometer *5*. The simplest psychrometer (Fig. 4) consists of two thermometers. One of the thermometers is kept dry while the bulb of the other is wrapped with wet cloth. As moisture evaporates and drains heat from the mercury of the thermometer, the reading of the wet thermometer will be lower than that of the dry one. The difference between the readings of the thermometers depends on the relative humidity of the air. With the aid of a psychrometric table (Table 1)

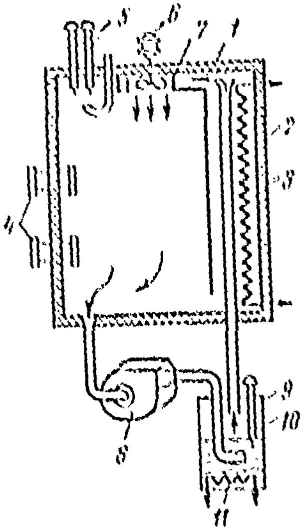

Fig. 3. Diagram of heat and moisture chamber

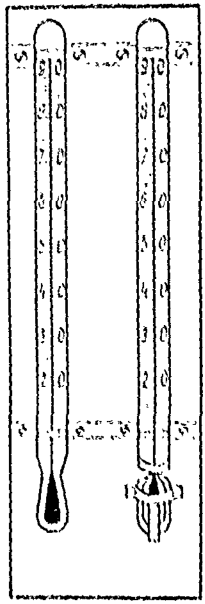

Fig. 4. Psychrometer

Table 1

Psychrometric Table

[illegible]	Difference between dry and wet thermometer readings, °C										
	0	1	2	3	4	5	6	7	8	9	10
	Relative humidity, %										
10	100	88	76	65	54	44	34	24	14	4	—
12	100	89	78	68	57	48	38	29	20	11	—
14	100	90	79	70	60	51	42	33	25	17	9
16	100	90	81	71	62	54	45	37	30	22	15
18	100	91	82	73	64	56	48	41	34	26	20
20	100	91	83	74	66	59	51	44	34	30	24
24	100	92	84	77	69	62	56	49	43	37	31
28	100	93	85	78	72	65	59	53	48	42	37
30	100	93	86	79	73	67	61	55	50	44	39

is possible to determine the relative humidity of the r on the basis of the thermometer readings. The table ives the values of relative humidity in per cents.

In heat and moisture chambers with automatic control of the air humidity, the psychrometer consists of two contact thermometers and is connected to an electronic circuit that controls the switching on and off of a centrifugal pump. When the relative humidity falls, the electronic circuit switches on the centrifugal pump which passes air through the humidifier, thus increasing the humidity in the chamber.

Pressure chamber. The pressure chamber (Fig. 5) is designed for testing the equipment at reduced atmospheric

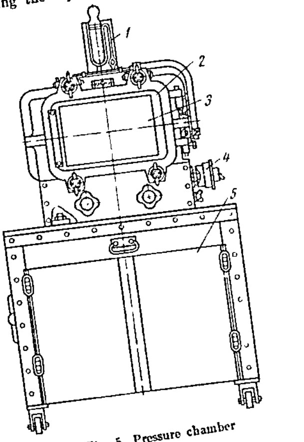

Fig. 5. Pressure chamber

In advanced pressure chambers provision is made for lowering the temperature so as to simulate more closely conditions in the upper layers of the atmosphere. The combination installations include devices for heating the air in the chamber, which do not differ in principle from those described above.

The equipment to be tested is put into the pressure chamber through door *2* which is hermetically sealed after the equipment has been installed and hooked up. The door has viewing window *3*. The air in the chamber is rarefied by means of a vacuum pump located in box *5*. The degree of rarefaction is measured by vacuummeter *1*. After completion of the tests, air is let into the chamber by means of special valve. For connecting the equipment to a power supply and to the measuring and testing instruments, the chamber is provided with hermetical leads *4*.

Fungi-formation chamber. This chamber is a combined heat and moisture chamber. Favourable conditions for the breeding of fungi are created in it by low mobility of the air and excluding the action of sun rays. Heated air circulates between the double walls of the chamber. The necessary humidity is obtained by free evaporation of water heated by the warm air.

The equipment under test and control dishes with nutritive medium are placed in the chamber. The equipment and the dishes are sprayed with an aqueous suspension of a fungi spore culture. After prolonged storage in the darkened chamber under conditions of increased temperature and humidity, the equipment is checked for operation, the absence of mould and corrosion, and for deterioration of galvanic and lacquer-paint coatings and contact connections.

The control dishes serve to ascertain that the fungi culture is viable. If, after testing, there are no traces of mould on the control dishes, both the dishes and the equipment must be sprayed again and the test for fungi resistance repeated.

Installation for moisture-resistance testing. This installation allows the equipment to be tested for watertightness, resistance to water, and rain.

Watertightness is checked by immersing the equipment in fresh or salt water to a certain depth.

When testing for resistance to water, the installation provides for the equipment under test to be subjected to powerful jets of water ejected under pressure from nozzles.

Rain is simulated by a system of pipes with a large number of small holes through which the water sprays out under pressure. Arranged under the pipes is a screen which breaks up the streams of water into separate drops. The water pressure necessary for rain- and water-resistance testing is produced by a centrifugal pump.

The installation includes a tank filled with water. The table on which the equipment under test is placed is turned slowly by an electric motor for the effect of the rain to be uniform.

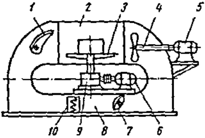

Fig. 6. Installation for dust-resistance testing

Installation for dust-resistance testing. To check the ability of the equipment to operate under the action of sand and dust, use is made of the installation shown in Fig. 6. The equipment under test is placed on table *3* in chamber *2*. Chamber *2* forms a part of closed air duct *8* in which air is circulated by fan *4* driven by electric motor *5*.

A dust mixture (quartz sand and kaolin) is introduced into the chamber. For the effect of the dust whirls on the equipment to be uniform, the table together with the equipment is rotated by electric motor *6* via reducing gear *9*. The temperature in the chamber is controlled by heater *10*. Shutter *7* controls the velocity of the air stream, and shield *1*, its uniformity.

Installation for sunlight-testing. Designed for checking the ability of the equipment to operate under the effect of a source of light close in spectral composition to sunlight, this installation is made in the form of a cabinet which is protected from the penetration of sunlight, when its door is shut (Fig. 7). The equipment under test is placed on rotating table *3*. The table is driven by electric mo-

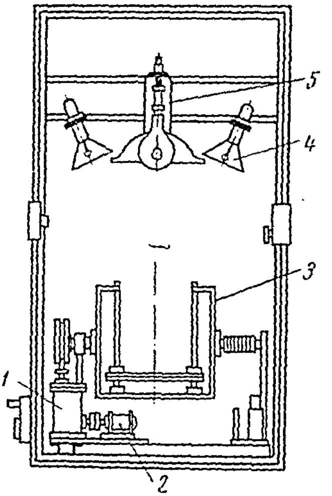

Fig. 7. Installation for sunlight-resistance testing

tor *2* via reducing gear *1*. As a result, all sides of the equipment are gradually irradiated by the sources of ultraviolet rays *4* and infrared rays *5*.

We have dealt only with the operating principle of installations for climatic testing. Modern testing equipment (especially combination chambers with large working volumes) is very complex. It includes systems of automatic control of the given test conditions and complicated equipment for creating a vacuum and for cooling air.

1.6. MECHANICAL TESTS

General. In mechanical tests the stability of operation of the equipment subjected to impacts, shaking, and vibration, as well as to linear acceleration, is tested. For such tests the equipment is mounted on special testing stands.

The conditions of transportation shaking are reproduced with the aid of impact and vibration stands. Impact stands simulate the impacts which occur during transportation across bad roads. Vibration of vehicles due to roughness of roads is simulated on vibration stands with oscillations of a non-sinusoidal shape, while vibration due to the operation of engines, on vibration stands, the oscillations of which are close to sinusoidal.

Linear acceleration can be obtained by testing the equipment on centrifuges. The equipment, rotating together with the platform of the centrifuge, is subjected to centripetal acceleration directed along the radius towards the centre of rotation.

The set of installations for mechanical testing includes

ing stands, measuring instruments, and auxiliary equipment.

The testing stands include a platform to which the equipment is secured rigidly and a mechanism which actuates platform in the appropriate way.

According to their purpose testing installations are divided into installations for testing:

for the effect of vibrational loads (vibration installations or vibration stands);

for the effect of linear accelerations (centrifuges);

for the effect of repeated impacts (impact stands);

for durability in transportation.

According to the operating principle, testing installations are divided into mechanical, electrodynamic, electromagnetic, piezoelectric, and electrohydraulic. The most widely used are mechanical and electrodynamic stands.

Testing installations are characterized by the frequency of the oscillations or impacts, amplitude, acceleration, and load capacity (the maximum weight of the equipment under test for the given installation). During mechanical testing the equipment may be in an operating or a non-operating state.

In the first case the equipment is energized and measuring instruments are connected for checking its operation under mechanical load. In the second case the equipment is de-energized and its operation after the effect of mechanical load is tested. The ability of equipment to remain operative after the effect of mechanical loads is known as *impact strength*, and after the effect of vibrational loads as *vibration strength*.

Many types of equipment have to operate under conditions of vibrational loads, hence the importance of tests for resistance to vibration, which reveal the ability of equipment to remain operative under conditions of vibration

Stationary equipment is usually tested for vibration an impact strength in respect to transportation condition

After any mechanical tests the equipment is examine externally and its operation is checked.

Let us examine mechanical tests in greater detail an primarily, the testing of equipment for vibration streng and vibration stability.

Parameters of Vibration and Their Measurement

In tests for vibration strength or vibration stability the equipment as a whole or its components are subjected to the force

$$F = ma$$

where m=mass
a=acceleration

The greater the mass of the equipment or of its components, the greater the applied force and, consequently, its mounting must be the stronger.

The mass of any radio equipment or of its components is quite definite and, consequently, the degree of mechanical overload is fully determined by the acceleration a or the load factor

$$j = \frac{a}{g}$$

where g=acceleration of the force of gravity equal to 9.81 m/s^2

If the vibration is sinusoidal, the acceleration varies periodically from zero to maximum. In this case the load factor is determined from the equation

$$j = \frac{\omega^2 S}{g} \approx \frac{2S}{500} \times f^2$$

where S=amplitude of the vibration, mm
ω=circular frequency of the vibration, rad/s
f=frequency of the vibration, Hz
g=acceleration of the force of gravity, mm/s^2

If the load factor is given, it is easy to determine the acceleration. Thus, for load factors of 2, 4, 6, and 8 we have the corresponding acceleration amplitudes of 2 g, 4 g, 6 g, and 8 g.

Sometimes the degree of mechanical overload in sinusoidal vibration is determined by the vibration frequency and its amplitude. In this case the load factor is determined from the indicated equation.

Vibration parameters are measured with the aid of vibrometric instruments: frequency meters, displacement meters (vibration meters), speedometers, accelerometers, tension

uges (deformation meters), and others. Wide use is made measuring devices based on the conversion of non-electrical magnitudes into electrical magnitudes. The vibration ensor is positioned so that its parameters (resistance, caacitance, etc.) are proportional to the measured vibration parameter (amplitude displacement, frequency, acceleraion, etc.). The output voltage of the sensor is amplified and applied to a recording device or measuring instrument.

The design of a number of vibration stands makes provision for measuring the amplitude of vibration with a microscope which is to be set up so that it will not be affected by the oscillations of the vibration stand. A metal mirror with cross hairs 1-3 microns thick is secured rigidly to the moving system of the vibration stand. A microscope is aimed at the cross hairs. When the vibration stand vibrates, the cross hairs become blurred to a width corresponding to twice the amplitude of the oscillations. The width of the blur is determined with the aid of the microscope.

The amplitude of the vibration is determined by the equation

$$S = \frac{(N-n)\,a}{2}$$

where N = number of divisions of the microeyepiece scre drum corresponding to the width of the blurre cross hair under vibration

n = number of divisions of the microeyepiece scre drum corresponding to the width of the cro hair in the absence of vibration

a = division value of the microeyepiece screw dr

Mechanical vibration stands. Figure 8 gives the diagr of a vibration stand with a reactive mass. Its oscillat system consists of two masses joined together by sprin The first mass includes platform P with equipment Q un test, and the second, reactive mass M with an actua device. When eccentric E turns, a centripetal force is veloped, which causes mass M to move in a vertical pl This motion is communicated to the platform via a sy of springs L and N. The oscillation frequency of the form may be controlled by varying the speed of the r turning the eccentric shaft; to control the amplitude

oscillations, the installation has provision for varying the working length of springs L and N.

The diagram of a centrifugal vibration stand is shown in Fig. 9. The non-balanced masses S are seated on shafts which are turned by an electric motor in opposite directions

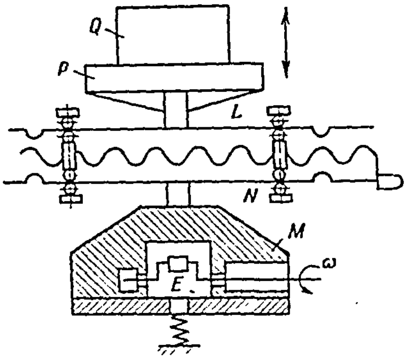

Fig. 8. Diagram of vibration stand with reactive mass

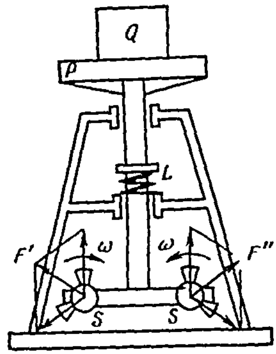

Fig. 9. Diagram of centrifugal vibration stand

at the same speed. With the sectors positioned with respect to each other as shown in the diagram, the horizontal components of the centripetal forces F' and F'' are mutually cancelled, while the vertical components add up, causing the platform to oscillate in the vertical plane.

When the initial position of the sectors is displaced, the resultant vertical component of the centripetal forces and, consequently, the amplitude of the oscillation of the platform P with the load Q will change. This is used for adjusting the amplitude of the oscillations by turning one of the sectors. The frequency of the oscillations is determined by the speed of the motor.

Electrodynamic vibration stands. Electrodynamic vibration stands are used for obtaining oscillations throughout a wide range of frequencies (from tens to thousands of hertzes). The simplest electrodynamic vibration stand (Fig. 10) has permanent magnet M, in whose air gap movable coil C is located. The coil is rigidly joined to platform P mounted on bosses of the magnet by springs N.

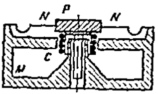

Fig. 10. Diagram of electrodynamic vibration stand

Alternating current is passed through the coil, it interacts with the magnetic field of the permanent magnet. Electromagnetic force F, which according to the rule of the left hand is directed either upwards or downwards, depending on the direction of the current in the coil, equals:

$$F = Bil$$

where B=magnetic induction in the permanent-magnet gap
i=instantaneous current value
l=length of the coil conductor

Sinusoidal variations in the current cause sinusoidal oscillations of the platform and load in the vertical plane. The amplitude of the oscillations depends on the weight of the equipment, force F, and the properties of the spring.

Centrifuges. The diagram of a small-sized centrifuge is shown in Fig. 11. The centrifuge is mounted on massive base *4*. Platform *2* is rotated by electric motor *3* which is coupled to the platform via a reducing gear. Plate *1* with

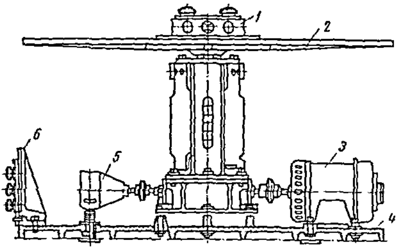

Fig. 11. Diagram of small-sized centrifuge

clamps allows the equipment under test to be secured to the platform at various distances from the axis of rotation.

Dynamo-sensor *5* is included in the circuit for measuring the rpm of the platform. To connect supply sources and measuring instruments to the equipment under test, the centrifuge shaft is fitted with slip rings. Contact with the rings is provided by brushes mounted on the stationary part of the centrifuge. The brushes are connected by wires to terminal board *6*.

When the platform with the equipment secured to it turns, a linear acceleration develops radially; it is determined by the equation

$$a_c = \omega^2 R$$

where R is the distance from the axis of rotation to the centre of gravity of the equipment under test.

Angular frequency

$$\omega = \frac{\pi n}{30}$$

where n is the number of revolutions of the platform per minute.

The linear acceleration can be adjusted by varying the number of turns n or distance R.

The load factor of the centrifuge is

$$j_c = \frac{a_c}{g} = \frac{\omega^2 R}{g} = \frac{\pi^2 n^2}{8.8 \times 10^3} R$$

In this equation the acceleration of force of gravity g is given in m/s^2 and distance R, in m.

Impact testing stands. These installations are designed for testing the equipment for impact strength. Platform P with equipment Q (Fig. 12) is periodically lifted by eccentric E and falls on shock-absorbers L. The eccentric is turned by electric motor M at the angular speed ω. The platform is mounted on guide pins N which travel in holes in support S and cause the platform to move vertically.

The load factor on impact depends on free-fall height H and the resilience of the shock-absorbers.

$$j_c = \frac{H}{S_g}$$

where S_g is the linear compression of the shock-absorbers on impact.

In addition to the load factor, tests for impact strength are also characterized by the impact frequency and the duration of the impact impulse. The impact frequency is equal to the rpm of the eccentric and can be easily determined with the aid of a tachometer. The compression of the shock-absorbers can be measured with the aid of a microscope or a stress gauge. Free-fall height H and the measured value of S_g determine the load factor for impact j_i.

To measure the duration of the impact impulse, a piezoelectric transducer and an electronic oscillograph can be used. The piezoelectric transducer is mounted on the platform of the impact stand. The voltage pulse which is developed in the transducer is fed to the oscillograph and photographed. Then with the photographic camera fixed with respect to the screen and the adjustment of the oscillograph unchanged, a sinusoidal voltage of a known frequency is photographed. The photographs of the current pulse and the sinusoidal oscillation taken in the same time scale make it possible to determine the duration of the impact impulse by comparing it to the period of the sine wave.

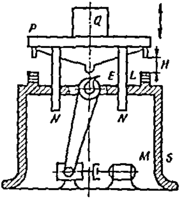

Fig. 12. Diagram of impact testing stand

The duration of the impact impulse can be adjusted by varying the thickness of the shock-absorber gaskets. For the acceleration amplitude not to vary in this case, it is necessary to vary accordingly the free-fall height of the platform.

1.7. ELECTRICAL TESTS

Electrical tests of the equipment include the measurement of the insulation resistance and checking its electrical

strength (breakdown test), as well as checking the dependence of the electrical parameters on variations in the supply mains voltage within given limits.

The quality of the insulation of the circuits may deteriorate with pollution, mechanical damage, etc. Especially dangerous is the deterioration of the insulation of circuits including high-ohm resistances: high-ohm voltage dividers and their loads, grid resistors of valves, etc.

If the insulation of such circuits is insufficient or the insulation resistance is low between tags on mounting strips, the contacts of valve holders, and other circuitry elements, high-ohm resistors are shunted, which causes the equipment to fail.

Measurement of insulation resistance. The insulation resistance is measured between separate circuits and between these circuits and earth. Such measurements are made both under normal conditions and in conditions of increased humidity, if provision for this is made in the specifications. Under normal conditions the insulation resistance of circuits usually exceeds 100 megohms, and with increased humidity, 10 megohms.

Specifications contain concrete demands to be met by the insulation of the given instrument or of its individual circuits, which sometimes may exceed 10-fold and even more the values of insulation resistance given above for both normal and increased humidity.

Insulation resistance is measured with the aid of a megohmmeter. The connection of a valve *megohmmeter* is shown in Fig. 13. Insulation resistance R_x is connected in series with standard resistor R_0, with $R_x \gg R_0$. This se-

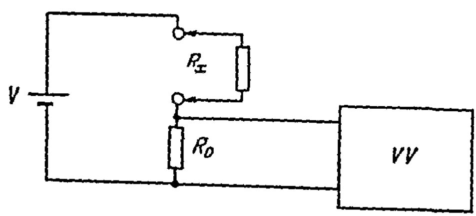

Fig. 13. Connection of megohmmeter

ries circuit is supplied from a stabilized source of direct current V. The current in the circuit

$$I = \frac{V}{R_x + R_0}$$

and the voltage drop across the standard resistor

$$V_0 = V \frac{R_0}{R_x + R_0} \approx V \frac{R_0}{R_x}$$

Valve voltmeter VV which measures the voltage drop across the standard resistor is calibrated in values of insulation resistance R_x.

By varying resistance R_0, it is possible to vary the insulation resistance measuring range. For example, if $V=100$ volts and the sensitivity of the voltmeter is 0.01 volt, then with $R_0=1$ kilohm, it is possible to measure resistance of $R_x=10$ megohms, and with $R_0=10$ kilohms, it is possible to measure insulation resistance of $R_x=100$ megohms.

Breakdown testing. The electrical strength of insulation is measured between separate isolated circuits and between these circuits and earth (chassis).

The test voltage is applied across the current-carrying conductors of isolated circuits or across each individual circuit and earth and maintained at the test value for one minute.

The test voltage, as well as the conditions under which the test is conducted, are stated in the Specifications for the given equipment.

In all cases the test voltage must exceed the working voltage. Approximate norms for test voltages are given in Table 2.

To test the electrical strength of insulation, use is made of breakdown installations which include a source of d.c. or a.c. voltage, the value of which can be varied from zero to the maximum value, and also a breakdown indicator. The breakdown indicators may take the form of measuring instruments, electric bells, or signal lamps.

The breakdown installations which include sources of both a.c. and d.c. voltage are called universal. Figure 14 shows the circuit of a universal breakdown installation. The mains voltage is fed to autotransformer Atr which

Table 2

Dependence of Test Voltage on Working Voltage

Maximum working voltage, V_w, volts	Test voltage, volts	
	under normal conditions	with increased humidity
Up to 100	500	250
From 100 to 30,000	$2V_w + 1{,}000$	$1.5V_w + 500$
Over 30,000	$1.5V_w$	$1.25V_w$

allows both the a.c. and the d.c. test voltage to be adjusted.

In breakdown testing with a.c. voltage, the circuit under test is connected between probes *1* and *3*, i.e., to the se-

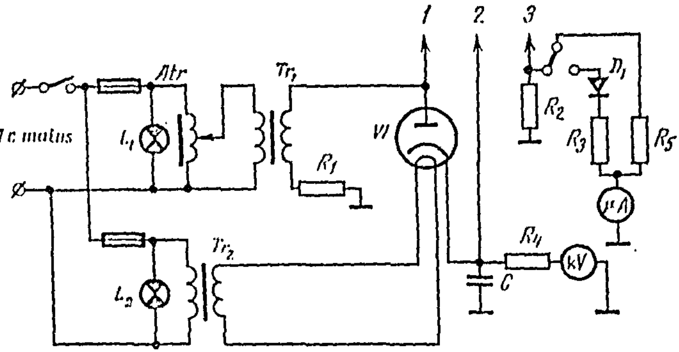

Fig. 14. Circuit of universal breakdown installation

condary winding of transformer Tr_1. In case of breakdown the following short-circuit is made: secondary winding of transformer Tr_1, circuit under test, and resistors R_1 and R_2. Resistor R_1 limits the loading of transformer Tr_1 and of the autotransformer in case of breakdown. Resistor R_2 is employed in the breakdown indicating circuit. The voltage dropping across this resistor causes deflection of the a.c. voltmeter made up of detector D_1, resistor R_3, and microammeter μA.

The value of the test voltage is set according to the kilovoltmeter, whose circuit includes high-voltage rectifier valve *V1*, resistor R_4, and moving-coil instrument *kV*. Connected in parallel to the instrument and resistor R_4 is capacitor *C* which is charged by the rectified current.

Rectifier valve *V1* is simultaneously used for obtaining the d.c. test voltage. Probe *2* is connected to its cathode. The equipment under test is connected between probes *2* and *3*. In case of breakdown, capacitor *C* discharges via

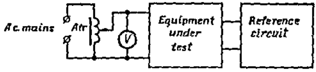

Fig. 15. Hookup for testing equipment at increased and reduced supply mains voltages

the broken-down circuit and resistor R_2. The voltage dropping across resistor R_2 causes deflection of the d.c. voltmeter made up of resistor R_5 and the microammeter.

The heater of rectifier valve *V1* is supplied from a separate transformer Tr_2, so that when the test voltage is adjusted, the heater voltage remains constant. Figure 14 does not show the protective devices which ensure safe operation of the installation. Among them is an interlock which automatically switches off the high voltage if the protective casing is removed.

Checking the effect of mains voltage on electrical parameters. The hookup for testing equipment at increased and reduced supply mains voltages is shown in Fig. 15. The supply voltage is adjusted with the aid of autotransformer *Atr* and set according to voltmeter *V*. The basic parameters of the equipment provided for in specifications are determined at various supply voltages.

1.8. ADJUSTING AND TESTING PROCEDURE

Adjusting and testing operations complete the manufacturing process of production of radioelectronic equipment.

In large-batch and mass *production* the adjusting operations are carried out at work places that come immediately after the work places for assembly and wiring operations.

The work places of the checking inspectors come after the work places of the adjusters. Such consecutive arrangement of the work places helps eliminate waste of time and effort for delivering the equipment from one work place to another.

In large-batch and mass production the equipment is often designed in separate units, which allows each unit to be adjusted separately. The units adjusted are passed on for general assembly. After general assembly final adjustment of the equipment is made.

If the equipment includes several devices forming a system, the enterprise provides work places for overall adjustment of the given system of devices.

Depending on the design of the equipment and the volume of production, the adjustment operations may be broken up into smaller operations, some of which can be carried out by less skilled workers.

In individual and small-batch production, the equipment, as a rule, is adjusted wholly by highly skilled workers.

Standard adjustment operations include three types of checking.

Electrical checking for correctness of assembly of the equipment. This operation is to check whether the components installed during assembly have been correctly wired and are in order.

To facilitate checking use is made of *check resistance charts* (Fig. 16). The charts indicate the resistance between various points of the circuit and the chassis of the equipment or the positive terminal of the anode-supply source. The value of the resistance at various points of the circuit is compared to the data of the check charts. Significant divergence indicates that either a mistake has been made in wiring, or the given circuit includes a faulty component (open-circuited resistor, a resistor of the wrong value, violated contact, etc.).

Checking and adjusting the operating conditions. Reliable operation of electronic valves, transistors, and certain other components depends to a great extent on whether the cor-

rect operating conditions have been established, for example, the value of the bias voltage applied to the grid of a valve. To facilitate checking and adjustment of operat-

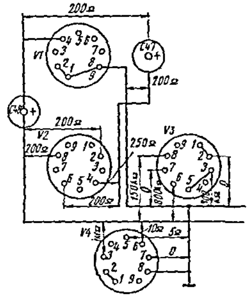

Fig. 16. Check resistance chart

ing conditions use is made of *check voltage charts* (Fig. 17). These charts are compiled from the results of voltage measurements made at the electrodes of valves and transistors in well adjusted and checked equipment which is regarded as standard. Voltage is measured between the check points and the chassis.

In case of significant divergence between the measured voltage and that indicated in the check voltage charts, the correctness of the wiring and the condition of the components are checked and, if necessary, the operating conditions are adjusted with variable resistors or certain components are replaced.

Adjustment of parameters. In these operations the parameters of the equipment are measured and adjusted to the values indicated in specifications. All operations are per-

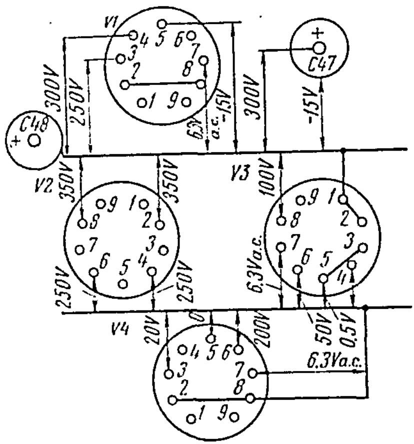

Fig. 17. Check voltage chart

formed in complete conformity with the process chart or the instructions for adjusting the given equipment.

Checking the equipment for conformity with the requirements of specifications in the technical inspection department completes the process cycle of production of the equipment. The head inspector seals the equipment and fills in its certificate which is delivered to the consumer together with the equipment.

1.9. SAFETY RULES FOR ADJUSTMENT

The greatest danger for adjusters is the high voltage which may cause burns, shock, and even death. The danger presented by electric current depends on the magnitude of the current, the frequency, the time during which a man is subjected to the current, the path along which it passes, and also on the state of health of the person.

Most dangerous is direct and low frequency current. Current exceeding 50 milliamperes may cause a shock. Currents from 50 to 100 milliamperes may cause loss of consciousness.

Current exceeding 100 milliamperes is lethally dangerous, as it can cause paralysis of the respiratory organs, damage to the heart, etc.

The magnitude of the current passing through the body depends not only on the voltage but also on the body's resistance. This resistance, in its turn, depends on the condition of the skin and the contact area. The specific resistance of dry and rough human skin at the place of the contact is 40-100 kilohms/cm^2, and of damp and injured skin, 800-1,000 ohms/cm^2.

The adjuster usually works with units or equipment with the protective casing removed. This increases the danger of electric shock. The safety rules include both measures for avoiding accidents and the first aid that should be administered to victims.

Highly dangerous is voltage applied to the hands of a man, as in this case considerable current is likely to pass through the area of the heart and sensitive nerve centres, which causes serious injury. This may occur, for example, when the adjuster touches the chassis with one hand and with the other, components or wires under high voltage with respect to the chassis. Care must be taken, when working under current is necessary, to use screw-drivers and other tools with well-insulated handles and not to touch the chassis or components of the equipment with the other hand.

An electric shock is possible when the chassis or a high-voltage point of the equipment circuit is touched with one hand.

In the case of certain faults the chassis of the equipment may carry high voltage. When the chassis is touched with a hand, an electrical circuit is made which includes the adjuster's body, his shoes, the floor, and the corresponding part of the equipment circuit. Reliable earthing of the chassis excludes the possibility of an electric shock when the chassis is touched. The earthing shunts the circuit: human body—footwear—floor—earth, and the voltage applied to this circuit becomes extremely low.

However, earthing does not exclude electric shocks when a high-potential point is touched. On the contrary, earthing only increases this danger. Actually, in this case the vol-

tage between the point of contact and the chassis is applied to the circuit: body—footwear—floor—chassis earthing wire.

To exclude the danger of an electric shock, the floor at the adjustment place should be made of non-conducting material such as dry wood, and if high voltage is on hand, whenever necessary, use is made of additional protective means: rubber gloves, rubber mats, etc.

All this goes to show that the magnitude of dangerous voltage depends on many factors. One can consider as safe a voltage of 36 volts, and in some cases 12 volts. As a rule, the soldering irons used for the assembly of radio equipment at factories are designed to operate on 36 volts.

With an increase in frequency the penetration of current into the body decreases, and correspondingly the danger it presents is reduced. High-frequency current spreads mainly over the surface of the body, causing burns.

When working with super-high frequency installations one may be affected by the electromagnetic fields radiated by the SHF generators, antennas, open waveguides. Systematic irradiation may cause headache, fatigue, an increase in body temperature. The effect of irradiation depends on its duration and intensity.

To avoid accidents it is necessary:

to give instructions and check the adjusters' knowledge of the safety rules;

to keep the work place, the tools, and clothes of adjusters in perfect order;

to check whether fuses, switches, and interlocks are in order;

when hooking up, to connect and manipulate measuring instruments only with the power switched off;

not to admit strangers to the adjuster's work place; prevent cases of leaving the work place unattended with the equipment open and energized;

before switching on and after switching off the equipment with open wiring, to discharge large-capacity capacitors with the aid of a discharger;

to connect SHF generators during alignment to matched loads, setting the lowest possible power output required for alignment;

not to make any manipulations in SHF channels with the generator switched on;

to make sure that the connections of elements in SHF channels are tight and reliable;

not to adjust energized high-voltage installations without rubber gloves, mats, insulated tools, and other protective means;

to check whether fire-fighting equipment and protective devices are in order;

to strictly observe the safety rules in force at the given enterprise, the shop, and the work place.

Review Questions

1. What kinds of inspection of radio equipment exist?
2. Into what groups is equipment divided according to its operating conditions?
3. How do mechanical, climatic, and electrical factors affect the operation of equipment?
4. How are climatic, electrical, and mechanical tests of radio equipment carried out?

CHAPTER II

Reliability of Radioelectronic Equipment and Methods of Ensuring It

2.1. STATISTICAL QUANTITIES. DETERMINATION OF RELIABILITY

No one can say beforehand just how long a radio set, television set, or any other radioelectronic equipment will operate without requiring repairs, or how often it will fail. The time of the operation of equipment until it fails pertains to that category of random quantities the laws of which are studied by the branch of mathematics known as the theory of probability.

At first glance it may seem strange to try and determine laws governing random quantities, but that such laws do exist can be easily seen.

Mix 70 white and 30 red balls in an urn. Take out one ball, look at its colour and put it back into the urn. Having repeated this experiment many times you will see that in about 30 cases you take out a red ball and in about 70 cases, a white ball. Consequently, the probability that in a single experiment a red ball will be taken out is $P_1=0.3$, and the probability that a white ball will be taken out is $P_2=0.7$.

We have cited a simple example when the conditions of the experiment can be precisely defined. But such a random quantity as the time of the operation of equipment until it fails depends on very many factors: the quality of the materials and parts, the skill of the makers, the culture of production, and many others.

In order to predict in such complex cases the probability of faultless (no-failure) operation over a given time, the probability of obtaining good or faulty equipment, the probability that the parameters of the equipment will keep

within the permissible limits, it is necessary to possess statistical data based on a large number of experiments. For example, on the basis of data supplied by repair shops performing guarantee repair of television sets, it can be concluded which types of television sets or which of their components fail oftener.

Such data is not enough to determine just how a certain television set or any of its components will behave in service. Maybe it will operate for a long time without failure, and maybe it will fail soon after going into service. But it provides the possibility of predicting which part of television sets in service will fail within a given period of time or what is the average life of a television set until its first repair.

The determination of such average data is the work of statistics. On the basis of statistical data on a previous batch of equipment, statistics can predict the average value of the parameters of the next batch of the equipment, if the production conditions have not changed significantly. Statistics can predict the percentage of rejects, the probability of certain departures in parameters, etc.

In recent years exceptional significance is being attached to increasing the reliability of radioelectronic equipment. This is due to the fact that radioelectronic equipment is becoming more and more complex and contains more and more components. Modern computers include tens of thousands of components. Failure of any one of them usually causes the whole machine to fail. An enormous quantity of components is also included in the radio equipment of rockets, radar stations, systems for automatic control of manufacturing processes.

In many cases the failure of a single component, such as a valve, a transistor, a resistor, or a capacitor, causes the whole system to fail.

The problem of increasing reliability is a complex task which can be solved only by the joint efforts of the enterprises supplying the materials and radio components and the assembly teams at the factories.

What is meant by reliability?

Reliability is a property of equipment (a device) to fulfill all its given functions under certain conditions of ope-

ration during a given time, while retaining its basic parameters within the limits stated in specifications.

Reliability is an important characteristic of the quality of equipment and of its operational properties. The time of no-failure operation of various samples of equipment of one and the same type is different. That is why those quantities which characterize reliability pertain not to a single article, but are average (statistical) quantities.

2.2. QUANTITATIVE CHARACTERISTICS OF RELIABILITY OF COMPONENTS

Radioelectronic equipment (receivers, transmitters, amplifiers) consists of many components: capacitors, resistors, transformers, electronic valves, transistors, etc. The reliability of equipment depends primarily on the reliability of its components.

The reliability of components is characterized by a quantity known as the *failure density*. To determine this quantity, a large number of components of the same type are tested for service life. Supply voltages are connected to the components so that they are under nominal operating conditions. For example, when testing resistors, their nominal power is dissipated in them; capacitors should be under the nominal voltage, etc.

Suppose during short time Δt in the process of testing, a small part ΔN of all the tested batch of components has failed. The failure density

$$\lambda = \frac{\Delta N}{N \Delta t}$$

where N is the number of components which continue to operate normally by the beginning of time interval Δt.

The failure of any component during time Δt is a random event, the probability of which, with a great number of tested components N and small time interval Δt can be determined from the equation

$$P_{\Delta t} = \frac{\Delta N}{N}$$

where ΔN = number of components that have failed during time Δt

N=number of components which continue to operate normally by the beginning of time interval Δt

Consequently, the failure density may be regarded as the probability of failure of components during a short single period of time:

$$\lambda = \frac{P_{\Delta t}}{\Delta t}$$

Theory and experience show that, if we exclude the initial period of testing of the components, then throughout a long time corresponding to the time of normal service, the failure density remains constant, while the number of components continuing to operate normally falls off exponentially (Fig. 18). Let us examine two identical periods of time $\Delta t_1 = \Delta t_2$. By the beginning of time interval Δt_1 there were N_1 components, and by the beginning of time interval Δt_2 there were N_2 components. As seen from Fig. 18 $N_1 > N_2$, but likewise $\Delta N_1 > \Delta N_2$. The failure density, however, remains the same in time intervals Δt_1 and Δt_2, i.e., $\lambda_1 = \lambda_2$ or

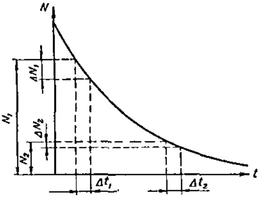

Fig. 18. Dependence of number of operative components on time

$$\frac{\Delta N_1}{N_1\,\Delta t_1} = \frac{\Delta N_2}{N_2\,\Delta t_2}$$

The constancy of the failure density of components in the period of normal service signifies that the number of components continuing to operate normally falls off exponentially.

Suppose that N_0 components have been put under test. The first component operated time t_1 until it failed, the second, time t_2, etc.

The average time of no-failure operation of the component (average service life)

$$T_{av} = \frac{t_1 + t_2 + \ldots + t_n}{N_0}$$

Observations show that for the period of normal service the failure density and the average time of no-failure operation are related by a simple ratio:

$$T_{av} = \frac{1}{\lambda}$$

2.3. DEPENDENCE OF FAILURE DENSITY ON SERVICE AND OPERATING CONDITIONS OF COMPONENTS

Identical components have different failure densities under different service and operating conditions. Table 3 gives the failure density of different components according to the conditions of service of various types of equipment: laboratory, motor-vehicle, airborne, shipborne, ground, and rocket (the table has been compiled on the basis of data given in foreign publications).

From the table it is seen that the failure density of components of the same type differs several hundred-fold, depending on the conditions of application. The component manufacturer indicates the failure density or the service life of components for definite conditions of service.

Let us suppose that we know the failure density of the components for normal conditions of service and we need to find out the approximate failure density for certain other conditions. Let us designate the failure density of a component under normal conditions λ_0, and the failure density under the given conditions λ; their ratio is known as the operating-conditions coefficient

Table 3

Failure Density of Components

Component	Failure density per 1 h of operation
Electronic vacuum devices	(0.001-0.345) 10^{-3}
Resistors	(0.00001-0.015) 10^{-3}
Capacitors	(0.00001-0.164) 10^{-3}
Transformers	(0.00002-0.064) 10^{-3}
Chokes, inductive coils	(0.00002-0.044) 10^{-3}
Relays	(0.0005-1.01) 10^{-3}
Selsyns, electric motors	(0.001-0.33) 10^{-3}
Semiconductor devices:	
diodes	(0.00012-0.5) 10^{-3}
transistors	(0.0001-0.9) 10^{-3}
Switching devices	(0.000003-0.028) 10^{-3}
Connectors	(0.00001-0.091) 10^{-3}
Soldered joints and wires	(0.0001-0.01) 10^{-3}

$$K_{cond} = \frac{\lambda}{\lambda_0}$$

The graph in Fig. 19 shows the approximate values of the operating-conditions coefficient for various equipment. The

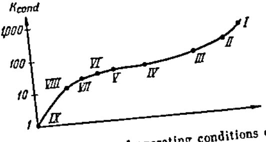

Fig. 19. Approximate values of operating conditions coefficient for various equipment

I—modern types of rockets; *II*—early types of rockets; *III*—aircraft; *IV*—high-altitude equipment; *V*—railway train; *VI*—motor vehicle; *VII*—ship; *VIII*—ground equipment; *IX*—laboratory conditions

failure density of components of *ground equipment* exceeds λ_0 ten times, motor-vehicle, ship, and high-altitude equ

ment, tens of times, airborne and rocket equipment, a hundred and more times.

In addition to the service conditions, the failure density of components is affected by their operating conditions: current, voltage, power dissipation. Capacitors usually fail due to breakdown, therefore the most important factor characterizing the degree of their loading is voltage. Resistors fail due to overheating, i.e., for them the dangerous factor is overloading in power consumption, etc.

In order to take into account the effect of operating conditions on the failure density of components, the conception *load factor* is introduced, by which is meant:

for resistors, the ratio of the power P dissipated in the resistor to its power rating P_{rat}:

$$K_{l.r} = \frac{P}{P_{rat}}, \text{ where } P = \frac{V^2}{R}$$

for capacitors, the ratio of the working voltage V to the voltage rating V_{rat}:

$$K_{l.c} = \frac{V}{V_{rat}}$$

for electronic valves, the ratio of the actual power dissipated on the anode P_a to the permissible power dissipation $P_{a.perm}$:

$$K_{l.v} = \frac{P_a}{P_{a.perm}}$$

For certain types of transformers, the load factor is expressed by the ratio of the power consumed by the transformer to its rated power.

Sometimes other evaluations of the load factor may be required. Thus, if the anode current of a pentode or a tetrode is low, while the screen-grid current is relatively high, the load factor should be determined by the ratio of the power dissipated on the screen grid P_s to the permissible power dissipation $P_{s.perm}$:

$$K_{l.v} = \frac{P_s}{P_{s.perm}}$$

The load factor of high-voltage transformers which consume little power is determined by the ratio of the voltage across the secondary winding to the permissible, etc.

Reduction of component load factors leads to an increase in size and weight of the equipment. When designing stationary equipment, for which size and weight are not of the prime consideration, load factors of about 0.5 can be recommended. With stringent requirements to the size and weight of the equipment, load factors close to 1.0 are selected. Overloading of components is not permissible as this leads to a sharp increase in the failure density. When adjusting the operating conditions of valves, transistors, and other components, the adjuster should not only strive to obtain the given parameters, but should also bear in mind that the component load factors should not exceed the permissible values. It should be borne in mind that the overloading of even a single component considerably increases the failure density of the whole equipment.

2.4. CLASSIFICATION OF FAILURES. DEPENDENCE OF FAILURE DENSITY ON TIME OF EQUIPMENT OPERATION

By *failure of equipment containing a certain number of components and fulfilling one or several functions* we shall designate such a fault, when the equipment ceases to fulfil at least one of these functions.

For example, by failure is meant the absence of sound or vision in a television set, the absence of power output or a modulator fault in a transmitter, the absence of voltage at the output of an amplifier when there is normal input voltage, the departure of one of the basic parameters beyond the limits established by specifications.

Failure of equipment is usually caused by the failure of one of its components. Failures are divided into *gradual* and *sudden*.

Gradual failures develop as the result of gradual alteration in the parameters of components with time: the gradual alteration in the resistance of resistors and in the capacitance of capacitors, reduction in the emission current of electronic valves, the wear of mechanical parts. Failures

of this type begin to develop rapidly a good time after the beginning of service, when the life of the components is drawing to an end. They can be eliminated by timely preventive repairs. The possibility of gradual failure occurring can be discovered by the readings of measuring instruments incorporated in the equipment, or during routine checking of the equipment for conformity with its specifications.

Sudden failures cannot be foreseen. They are the result of rapid alterations in a component, which lead to its failure. Among sudden failures are breakdown of insulation, burning out of filaments, etc. Such failures are usually the result of latent defects in components, materials, and circuitry. A typical curve of failure density plotted against the time of operation of equipment is shown in Fig. 20.

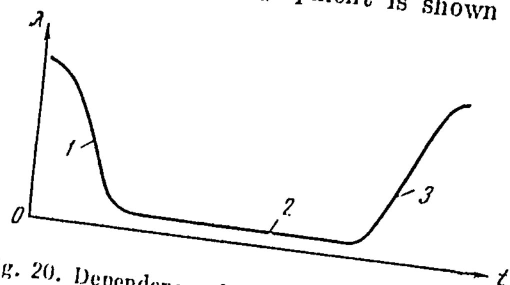

Fig. 20. Dependence of failure density on time of operation of equipment

The first section *1*, the running-in time, is characterized by a high sudden failure density that rapidly falls off with time. The longest section *2* corresponds to the period of normal operation, when practically all the failures are also sudden. Characteristic of this period is the constancy in the failure density. Section *3* is characterized by increasing failure density due to increase in gradual failures caused by the service life of the components coming to an end.

The failure of radioelectronic equipment is due mainly to the failure of electrical components and, primarily, of electro-vacuum devices, which account for about 50 per cent of the failures of equipment. Substantial failures are

due to breakdown of capacitors, burning-out of resistors, violation of the electrical strength of the insulation of transformer and choke windings, breaks in windings, burning of relay and switch contacts.

A great portion of sudden failures is due to low production culture at factories manufacturing radio components. Violation of manufacturing process, inconformity of starting materials to requirements, insufficient cleanness in production premises—all this leads to the appearance of defects which are often difficult to discover during the testing of components at the Manufacturer's.

A significant portion of sudden failures of components is due to mistakes which developed during designing of the equipment, violation of the operating conditions of components in the process of adjustment, latent defects in assembly and hookup of the radio equipment. There is a great difference between failure of equipment during its production and during its service. It is much cheaper and easier to eliminate faults at the Manufacturer's, because there are skilled adjusters who know the equipment well and have at hand the spare parts and the devices necessary for quickly finding and eliminating the fault.

Figure 20 shows that most of the failures occur during the running-in period, especially its beginning. For the running-in period not to occur during the service life of the equipment, manufacturers practice running in of fully adjusted equipment under normal operating conditions. The running-in time is established experimentally on the basis of the purpose of the equipment and the results of its tests for reliability.

In addition to the running in of equipment, training of its various components is employed. The components to be subjected to training are selected on the basis of reliability tests of the equipment. Components which fail oftener than others and whose running-in time exceeds that of the equipment as a whole, are trained under operating conditions before installation in the equipment. Components arriving from suppliers are usually trained in incoming inspection laboratories, and then they are delivered to the assembly shops. Components made at the factory are trained before final checking by the inspectors. Such a system reduces the

probability of delivering the components to assembly shops without training.

Preventive repairs can exclude the third section of the failure-density curve. To discover gradual changes in parameters in good time, the equipment incorporates measuring instruments and test jacks which facilitate regular checking of the circuit operating conditions and discovery of impermissible changes in parameters.

During the period of normal service, which corresponds to section *2* of the failure-density curve, the failure density is constant ($\lambda = \text{const}$).

For the period of normal service the failure density of equipment not provided with standby circuits is equal to the sum of the failure densities of its components:

$$\lambda_{equip} = \lambda_1 + \lambda_2 + \dots + \lambda_n$$

where λ_{equip} is the aggregate failure density of the equipment (λ_1, λ_2, etc.).

Even a single unreliable component can sharply increase the failure density of the whole equipment. Therefore, when adjusting radio equipment special care should be taken to create light conditions for less reliable components by providing them with better shock-absorption, removing them from overheating components, etc.

The least reliable components are discovered during the processes of adjustment, running-in, and testing of the radio equipment, therefore in each particular case it is necessary to ascertain why this component is less reliable, and what measures should be taken to reduce the danger of its failing. Special attention should be paid to vacuum and semiconductor devices, the failure density of which depends to a great degree on the quality of the assembly and adjustment of the equipment.

5. EXPONENTIAL LAW OF RELIABILITY

The failure density λ characterizes the probability of failure of the equipment within a short single interval of time. But one is usually interested in the probability of no-failure operation of the equipment during a certain gi-

ven service time t. The requirements to the time of no-failure operation of the equipment may differ widely. For instance, the radio equipment of a rocket is to operate without failure for a much shorter time than the radio equipment of an aircraft.

The specifications for equipment usually state the probability of its no-failure operation during a certain time. The same components are usually employed in various devices, and they are to meet different requirements in respect of no-failure operation time. Consequently, knowing the basic parameter of reliability of a component, i.e., its failure density λ, it is possible to determine the probability of its operation without failure during any given time t.

The dependence of the probability of no-failure operation on time (during the period of normal service) is determined by the exponential law of reliability.

$$P = e^{-\lambda t}$$

where P = probability of no-failure operation of the component during time t

λ = failure density of the component

t = given time of no-failure operation

e = base of a natural logarithm

This law is shown graphically in Fig. 21. From the figure it can be seen that the longer the given time t, the less the probability that the component will not fail during this time.

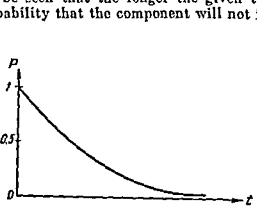

Fig. 21. Exponential law of reliability

The probability of no-failure operation of intricate eq
ment is also determined by the exponential law

$$P=e^{-\lambda t}$$

The longer the equipment must operate without failu
the more difficult to ensure a given probability of no-fa
lure operation for the given time. For example, if an auto
matic radio station is serviced by a mobile team once
year then the given time of no-failure operation should no
be less than one year. Over this time the probability of
failure of the automatic station should be sufficiently low.
The mobile team must carry out preventive repairs and
replace all those components whose service life is running
out.

One must differentiate between equipment used once and equipment that is repeatedly used. Single-use equipment operates up to the first failure. Among components of this kind are vacuum devices, resistors, capacitors, semiconductor devices, which after failure are replaced by new ones. If whole units and instruments due to the conditions under which they operate or any other reason are not subjected to repairs, they can also be referred to the single use equipment. Multiple-use equipment is repaired afte
failure, and its ability to operate is restored.

For single-use equipment, by *time of no-failure operation* is meant a given time of operation up to the first failure. For multiple-use equipment time interval t is set between two failures and the probability that the time interval between two failures exceeds the given value is determined from the exponential law of reliability.

One should differentiate between the average time between two failures T_{av} and the given time of no-failure operation t.

If time t is equal to T_{av}, then the probability of no-
ilure operation during time t will be low. Indeed, from
e exponential law of reliability it follows that at $t=T_{av}$

$$P=e^{-\frac{t}{T_{av}}}=e^{-\frac{T_{av}}{T_{av}}}=e^{-1}=0.37$$

he lower the value of t in comparison to T_{av} th

ter the probability of no-failure operation and vice versa. To ensure high reliability, i.e., a probability of no-failure operation close to unity, especially over a long time, is a difficult problem. Let us examine the ways of solving it.

2.6. WAYS OF INCREASING RELIABILITY

Reliability depends on the design of the equipment, the manufacturing process, and its proper maintenance.

There are several ways of increasing the reliability of equipment.

Decreasing the number of components. For solving one and the same technical problem, it is possible to employ various versions of circuits. The simpler circuits ensure a higher reliability because they require a smaller number of components. But it is not only the number of components that determines the version. Practice has shown that adjusters help designers introduce many improvements into the design and, in particular, decrease the number of components, especially in experimental and small-batch production.

Replacement of insufficiently reliable components with more reliable ones. The process of adjustment and testing of radio equipment brings to light mistakes made in designing, which noticeably reduce reliability. These may be insufficient insulation which causes breakdowns, wrongly selected electrolytic capacitors which fail at low temperatures, wrongly selected shock-absorbers, etc.

Adjusters are usually well aware of such weak points in the design, and their suggestions for replacing insufficiently reliable components may be of great value.

Use of various methods for reducing the effect of climatic and mechanical factors. If the components installed in the equipment possess a high failure density under certain service conditions and there are no suitable, more reliable components, it is necessary to reduce the effect on these components of those factors which cause a sharp increase in the failure density. The effect of vibration, impacts, and acceleration can be reduced by employing shock-absorption of a whole unit or of separate components, by changing the inherent frequency of vibration, impro-

ving mechanical mounting and the quality of solder joints, by more rationally locating the equipment.

The effect of high temperature can be reduced by improving cooling conditions and more rationally arranging those components that are sensitive to temperature variations.

The effect of reduced atmospheric pressure, high humidity, sand, and dust can be excluded or reduced by employing hermetical sealing, impregnation, sealing, encapsulating, by applying protective coatings, etc. The use of these methods of increasing reliability entails greater or lesser expenditures and the problem is to select the cheapest.

Correct choice of component operating conditions. The choice of minimum voltages and powers of supply sources for the given dimensions and weight of the equipment makes it possible to create light operating conditions for the components, reduce heating inside the equipment and, consequently, to reduce the danger of failure.

As an example of wrong selection of operating conditions one can cite the case when in a voltage amplifier the d.c. component of the anode current exceeds many times the a.c. component, because an unduly low bias voltage has been selected with an unjustifiably high voltage at the anode. As a result there is a high d.c. component of the anode current and high power dissipation on the valve anode. Sometimes there is an unduly high dropping resistance in voltage regulator circuits, in filters of the *RC* type, an unjustifiably high power consumption in voltage dividers.

Thorough calculation of the circuit with the aim of employing the minimum voltages and powers and experimental checking of these calculations are an important requisite for increasing reliability. In the case of rigid requirements to the size and weight of the equipment, load factor should be chosen 0.5-0.7. This reduces the danger of failure of components in comparison to nominal operating conditions.

Proper adjustment of equipment. An adjuster should remember that the parameters of components vary under the action of external factors and throughout the time of ... Changes in the parameters of components bring

about a change in the overall parameters of the equipment, as indicated in the specifications. These changes should not lead to failure of operation, therefore one should try to keep the equipment from failing to operate even with certain displacement of the controls to both sides of the position corresponding to the nominal parameter value.

Redundancy. In recent years wide use is made of redundancy of the least reliable components, units, and assemblies. The standby facility carries on the functions of the main facility, if the latter has failed. It may duplicate the function of the operating facility or be connected only after it has failed. The standby facility is usually connected automatically. Redundancy increases the cost of equipment, but considerably increases the probability of its no-failure operation, i.e., its reliability.

Reducing the time spent for eliminating faults. When using multiple-use equipment, it is very important to reduce the time spent for eliminating faults. To reduce idle time of the equipment, when designing, special attention should be paid to providing convenient access to the circuit components, to the use of built-in instruments which facilitate checking of operating conditions and finding of faults, to providing test jacks for connecting measuring instruments to various points of the circuit.

Such measures not only reduce idle time in cases of failure and preventive repairs but also reduce the cost of servicing the radioelectronic equipment. In the case of automatic control systems and electronic computers, the economic effect of reducing the loss of time is very great due both to the idle time of expensive equipment and the dead time of the attending personnel.

Reliability of equipment provided for in designing must be ensured during its production. There are the following ways of ensuring reliability during the process of production:

raising the culture of production, strict observation of process regimes, regular checking of measuring instruments and devices, tools and accessories, cleanness of the work place;

100 per cent or sampling inspection of incoming materials or articles arriving from suppliers (in case of impro-

per transportation and storage various defects may develop; in addition, mistakes may be made by the workers of supply bases);

raising the skill of employees, their understanding of reliability requirements and methods of eliminating the failure density of components, assemblies, wiring and assembly connections, and the equipment as a whole;

the employment of training of separate components and running-in of the equipment (it is desirable that the period of running-in of the equipment should pass mostly at the Manufacturer's, which decreases the failure density of the equipment during service);

modernization of the equipment with the aim of increasing its reliability on the basis of data provided by the consumers, repair organizations, as well as on the basis of the results of testing the equipment at the Manufacturer's;

improvement of the system of checking the quality of the operations performed, all possible incentives for employees who increase the reliability of equipment.

Extremely important for maintaining the reliability of equipment is proper operation, for which it is necessary to:

ensure a high quality of the documentation passed on to the consumer together with the equipment (the operating instructions of the equipment should clearly explain the operating principles and should include circuit diagrams and the necessary data on the arrangement of the components of the equipment and its test points, as well as data on normal operating conditions, instructions for conducting preventive repairs, and other necessary information on servicing the equipment);

study and strictly observe the rules for operating the equipment.

Review Questions

1. What is meant by the reliability of radio equipment and what is it characterized by?
2. In what way does reliability depend on the complexity of equipment?
3. What is meant by the load factor?
4. What ways of increasing reliability exist?

CHAPTER III

Fundamentals of Adjusting and Testing Technology

3.1. DEVELOPMENT OF ADJUSTING AND TESTING TECHNOLOGY

The manufacturing process of adjustment consummates the production of radioelectronic equipment. The basic documents used by an adjuster are technological charts or adjustment instructions. These documents are compiled on the basis of specifications, but they can contain more strict parameter tolerances. This is due to the fact that equipment is adjusted under normal conditions and the margin of tolerances ensures stable operation of the equipment under actual conditions and over a certain period of time.

One of the most labour-consuming tasks of adjustment is checking the operation of the equipment and finding and elimination of faults. To facilitate these operations it is necessary to have circuit and wiring diagrams, as well as voltage and resistance charts.

The adjustment of equipment is divided into a number of operations. The greater the volume of production, the more expedient is it to increase the number of adjustment operations, to use less qualified labour, and to increase productivity. However, adjustment operations can be broken up only as long as each of them remains more or less independent. Usually the following operations are differentiated:

checking of operating conditions, finding and eliminating faults;

adjustment of individual units (according to the number of units which can be adjusted independently);

overall adjustment.

To ensure the given production program, it is necessary to equip several work places for each operation. The number of identical work places is determined on the basis of the laboriousness of the operation, the production program, and the number of work shifts. Obviously, the more labour-consuming operations require a greater number of work places.

Some devices or units may have such faults that cannot be eliminated in the time given for the operation. Not to hold up the normal course of the manufacturing process (for example, the operating rhythm of the conveyer), it is expedient to have special work places for checking and adjusting such equipment. These work places should be manned by the most skilled adjusters, able to find and eliminate defects, the discovery of which requires good theoretical knowledge and practical experience. In case there is no equipment with intricate defects, the highly skilled adjuster can replace any worker on any other operation.

Equipment is tested on the basis of the specifications. The testing program is compiled so as to ensure high reliability of the testing. By testing reliability is meant the probability that equipment having undergone testing will conform fully to the requirements of the specifications.

High testing reliability is ensured by the correct choice of the testing technique and of the measuring and testing equipment, by systematic checking of its condition, and strict adherance to the testing program and technique.

Development of adjusting and testing technology includes:
compilation of a list of operations;
elaboration of a testing technique;
selection of universal measuring instruments;
development (if necessary) of non-standard testing equipment, as well as the designing of work places.

Testing operations are performed at work places by both quality inspectors and adjusters. The adjuster must not only measure the parameters of the equipment, without which it cannot be adjusted in general, but must also check, when necessary, the effect of various climatic, mechanical and electrical factors on the operation and parameters of the equipment. Thus, for example, when adjusting a master oscillator, the frequency drift with variation in tempe-

rature and the absence of parasitic frequency modulation during vibration are checked.

Adjusting and testing technology is refined by the designers and the producers at all stages of designing of the equipment.

During the designing of the equipment, the parameters are measured, as a rule, with the aid of universal measuring instruments. Parallel development of highly efficient testing stands and allowance for their peculiarities when designing samples of the equipment effect a significant economy and reduce the time necessary for putting the equipment into production.

When developing a testing technology, it is necessary to ensure reliable testing of batches of the equipment and the least possible expenditure for checking it.

Extension of the testing volume (the number of articles in a batch that are to be tested) and growth of the number of checking operations increase the testing reliability but at the same time increase their cost. Taking into consideration these two factors, i.e., reliability and cost, it is possible to find the optimal variant providing sufficiently high checking reliability of batches of the equipment at the minimum cost.

The cost of testing operations depends primarily on the proportion of the articles that are subjected to experimental checking. In the case of individual and small-batch production it is usual to check 100 per cent of the equipment, i.e., to check each article for conformity with the specifications. In batch production wide use is made of sampling inspection. In sampling inspection only a certain part of the batch is checked and the fitness of the whole batch is judged on the basis of the inspection results.

The correct choice of electrical parameters of the given equipment, which are to be checked is of great economic significance. To facilitate testing as much as possible it is necessary to choose a minimum number of complex parameters, checking of which confirms that the equipment operates normally. Each of the complex parameters must provide checking of the operation of many components.

Thus, checking a receiver sensitivity makes it possible to discover non-conformity of valves to specifications,

faults of the anode and grid supply circuits, of intermediate frequency filters, etc. Checking a television set with the aid of the test pattern makes it possible to discover failures and non-conformity to specifications of components of the vision channel, the scanning and synchronization circuits. Measuring the no-load current of a transformer makes it possible to discover many defects in the materials and assembly of the transformer.

Thus, the choice of a minimum number of complex parameters, checking of which ensures the necessary checking reliability of the equipment, is highly significant for reducing the cost of checking.

Analysis of the statistical data on the failure of bought radio components helps organize correctly the checking of incoming components of the equipment. Incoming inspection is of the sample type as a rule, and determination of the size of the sampling significantly affects its cost.

No less important is the choice of the parameters of the incoming components that are checked. It should be taken into consideration that the incoming components have been tested at the Manufacturer's. In a number of cases it is sufficient to check the documents of the components and to examine them externally. In other cases all or a part of the bought components are checked for one or several parameters.

Analysis of the statistical data on the failure of components of the given equipment may show that it is worthwhile to organize training of individual components of the equipment in order to increase their reliability.

The content and sequence of acceptance tests is determined by the requirements of the specifications which usually provide for the checking of each article for the minimum number of complex parameters that makes it possible to judge of its operation.

Periodic (check) tests are always of the sample type; they include the checking for conformity with the specifications of a small part of the batch in all parameters under various climatic and mechanical conditions. The test program is compiled on the basis of the specifications and the testing standards. The program sets the number of samples, the volume, the sequence and the time for conducting tests

for the effect of various climatic, mechanical, and electrical factors and contains references to the corresponding items of the specifications and standards.

The most labour-consuming part of the process of adjustment and testing is taken up by various measurements which are made when checking the operation of the equipment and adjusting it. The efficiency and quality of these operations depend to a great extent on the facilities of work places.

3.2. WORK PLACES FACILITIES

Requirements to be met by facilities of work places. The work places for adjustment and testing should meet the following requirements:

1. They should include the measuring and testing devices necessary for checking all the parameters stipulated by the specifications.

2. The devices used should be reliable, possess stable parameters, and ensure:

high labour productivity;

simplicity, safety, and economy of attendance;

the same measurement results of the same parameters at different work places;

minimum dependence of measurement results on outside factors.

3. The measuring and testing devices should be checked at the set times, they should have a certificate into which the data on checking them for conformity with the specifications is entered.

4. To reduce the time of adjusting and testing, the measuring and testing devices should have the minimum number of controls. After the measuring and testing devices are arranged at the work place, there should remain sufficient space for installing the equipment to be tested. It is important to have convenient connections between the input circuits of the equipment under test and the appropriate supply sources and measuring instruments. For this purpose use is often made of the connectors built into the equipment under test.

5. They should conform to the safety rules.

6. The work place should be a part of the overall technological cycle and situated so as to avoid unnecessary moving about of the equipment under test.

The above requirements can be met more fully when designing special benches intended for checking the parameters of the given equipment.

Test benches. Checking of parameters of the equipment includes the following operations:

connection of supply sources, input signal sources, and measuring instruments to the equipment under test;

setting of the given parameters of input signals;

reading the parameters of the equipment from measuring instruments or indicators.

For example, to check a standard radio frequency amplifier, it is necessary to supply power to its anode, grid, and heater circuits, to apply an input voltage from a radio frequency oscillator and, setting various voltages at the amplifier input or output, to take the readings of the measuring instruments.

In batch and mass production a significant reduction in adjustment and testing time is obtained by the use of special benches designed for checking one or several parameters of the equipment. The greatest economic effect can be achieved by using automatic benches for comprehensive checking of the equipment in all parameters. The design and manufacture of such benches is expensive and is justified only under the conditions of large-batch and mass production.

Semi-automatic and manually controlled benches can be effectively used both in large-batch and small-batch production. They are widely used for checking the accuracy of assembly and the operating conditions of valves and semiconductor devices and for checking the parameters of individual assemblies and units. The requirements pertaining to the facilities of work places can be fully applicable to test benches.

A shortcoming of most test benches, including automatic and semi-automatic ones, is their rapid moral wear.

The improvement of radioelectronic equipment and the modernization this entails may be the reason why a bench has become useless and its remodelling economically un-

profitable. In mass production the service life of a test bench is usually sufficiently long to justify the expenditures for its designing and manufacture. In small-batch production a specialized bench may prove a loss if its service life proves considerably shorter than was estimated during its development. With the advance of modern technology, it has become feasible to develop radically new benches (with programmed control) which can be quickly readjusted in case of modernization of the tested equipment or even for crossing over from the checking of one type of equipment to the checking of another type.

In batch and mass production voltage is supplied to the work places *from a central source. In the case of such a* system, the sources of various signals necessary for testing the equipment are not located at the work place but separately and connected to the work places by connecting cables. The amplitude of the voltages supplied to the work places can be checked and controlled within necessary limits at the work places. Centralized supply of voltages to the work places has a number of advantages: it is not necessary to have generators at each work place and to adjust their frequency or pulse duration. The work place becomes more spacious, the time spent for adjustment and checking is reduced, checking of the correct setting of input signals is made easier, and adjustment becomes more stereotype.

3.3. CHOICE AND CONNECTION OF MEASURING INSTRUMENTS

Choice of instruments. *In experimental and small-batch* production the measuring equipment is selected, as a rule, *from standard, universal measuring instruments,* the specifications of which are given in reference books and catalogues. *After the successful testing of experimental* samples of mass-application equipment, there often arises the need of developing special-shop instruments which increase the productivity of adjusters and testers of radio equipment. *The development of such instruments and their* manufacture is included in the technological preparation for large-batch and mass production. Work on the development and improvement of special measuring instruments

and test benches usually continues throughout the process of production of equipment.

The initial data for choosing measuring instruments or developing special measuring instruments are the specifications of the equipment to be tested, i.e., input and output impedance, the range of working frequencies, pulse durations, sensitivity, accuracy requirements to output parameters, etc., as well as the equipment production program. The expedience of developing special testing instruments is determined by the cost of developing and production of it and the economy that the use of the given instrument will effect. One should also take into account the possibility of using the instrument in case of modernization of the equipment to be tested and in testing other types of equipment (possibly after certain alterations).

When selecting a universal measuring instrument, its cost, productivity, and size should be taken into account. Thus, instruments for observing and measuring frequency responses are more expensive and bulk than measuring oscillators, but they help raise the productivity of the adjuster. The parameter measuring accuracy should correspond to the requirements of the specifications, the adjustment instructions, or to the technological chart.

In batch and mass production all the adjusting and checking operation, as well as the measuring instruments, their connection and arrangement on the work place are strictly specified by appropriate documents. Strict adherence to the requirements of the adjustment instruction or the technological chart is just as important as the observance of technological discipline in carrying out any other operations.

In experimental, piece, and small-batch production detailed documents covering the adjuster's work place can be absent. Therefore, a highly skilled adjuster must be able himself to select the measuring instruments and connect them properly.

From the specifications of the equipment to be adjusted or checked, the following is usually known:

the value of the parameter (current, voltage, capacity, power, etc.) and the permissible departure from this value;

the frequency range within which the equipment operates;

the values characterizing the input or output impedance of the equipment: input (output) capacitance, input (output) resistance.

Consulting a reference book on radio measuring instruments, it is necessary to *find the instrument which is suitable:*

in the range of measured values (the measuring range of the instrument must significantly exceed the range of values of the parameter to be measured, with a margin both in the direction of lower and higher values);

in frequency range (the frequency range of the instrument *should fully cover the range of working frequencies* of the equipment to be checked);

in measuring accuracy (the accuracy of the instrument should be several times higher than the permissible departure of the parameter from the rated value. It is usually sufficient for the accuracy of the instrument to be three times higher than the permissible departure of the parameter. However, more **stringent requirements** are *possible.* For example, *in many cases it is necessary that the* frequency measuring accuracy be at least 10 times higher than the permissible frequency departure of the oscillator being checked);

in internal resistance (the internal resistance of the measuring instrument should be such that its connection *only slightly affects the operating conditions of the equipment being checked).*

To judge to what extent connection of the instrument affects the operating conditions of the circuit to be checked, it is necessary to compare the internal resistance of the instrument to the resistance of the tested equipment, as measured between the points of connection of the instrument.

If *a measuring oscillator is connected to the equipment,* its output impedance is compared to the input impedance of the equipment. If a vacuum-valve voltmeter is connected to the output of an amplifier, its input impedance is compared to the output impedance of the amplifier. In most cases it is considered permissible to connect an *instrument in series with a circuit if its internal resistance*

is 10 times less than the resistance of the circuit, i.e., the following inequality is observed:

$$Z_{in} \leq \frac{1}{10} Z_{ctr}$$

where Z_{in} — internal impedance of the instrument
Z_{ctr} — impedance of the circuit measured between the points of connection of the instrument

If the instrument is connected in parallel to the circuit, in most cases it is necessary that

$$Z_{in} \geq 10 Z_{ctr}$$

This practical rule should not be considered universal. It is not applicable, for example, when a voltmeter or oscillograph is connected to a tuned circuit of a resonance amplifier, because the input capacitance of the instrument disturbs the resonance and the operating conditions of the amplifier change sharply.

The internal impedance of most measuring instruments is of a capacitive nature and can be represented by the equivalent circuit shown in Fig. 22*a*, where R_{in} is the input

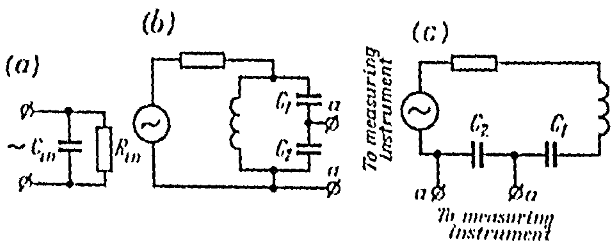

Fig. 22. Connection of measuring instrument to circuit under test

(*a*) equivalent circuit of instrument; (*b*) division of capacitance in parallel oscillatory circuit; (*c*) division of capacitance in series oscillatory circuit

(output) resistance of the instrument, C_{in} is the input (output) capacitance of the instrument. On connecting a voltmeter or an oscillograph in parallel to a resonant circuit, the resonance frequency as well as the Q-factor of the circuit decreases, there is also a change in its frequency response and in the amplitude values of currents and voltages.

The effect of the measuring instrument may be decreased by dividing the tuned-circuit capacitance into two series-connected capacitors C_1 and C_2 (Fig. 22*b* and *c*), while observing the inequality $C_2 \gg C_1$. Of course, in this case division of the tuned-circuit capacitance and the leads *aa* must be provided for while designing the equipment to be checked.

There are a number of other methods of reducing the effect of the internal impedance of the instrument. Let us examine the following methods:

shunting the instrument and connection of a series resistor;

use of voltage dividers;

creation of actual operating conditions with respect to the input or output when adjusting separate units of the system;

matching impedances when connecting measuring instruments to SHF channels.

Shunting the instrument and connection of a series resistor. The instrument, when connecting in series in a circuit, is shunted by a sufficiently small resistor R_{sh} (Fig. 23*a*) or by a sufficiently large capacitor C_{sh} (Fig. 23*b*) in order to slightly affect the circuit operating conditions. In this case the following inequalities are observed:

$$R_{sh} \ll R_{in}; \quad R_{sh} \ll R_i + R_c; \quad C_{sh} \gg C_{in}; \quad C_{sh} \gg C_{cap}$$

where R_c = resistance of the coil

R_i = internal resistance of the oscillator

C_{cap} = capacitance of the tuned-circuit capacitor

A measuring instrument with an insufficiently high internal impedance is connected in parallel to the test circuit via small capacitor C_s (Fig. 23*c*).

Let us examine several cases.

Figure 23*d* shows a circuit for measuring the a.c. component of the cathode current of a valve by means of an oscillograph. Resistor R_{sh} is low compared to cathode resistor R_k, and its inclusion has practically no effect on the operating conditions of the valve. Having measured with the oscillograph voltage V_{sh} across resistors R_{sh}, we determine cathode current $I_k = V_{sh}/R_{sh}$.

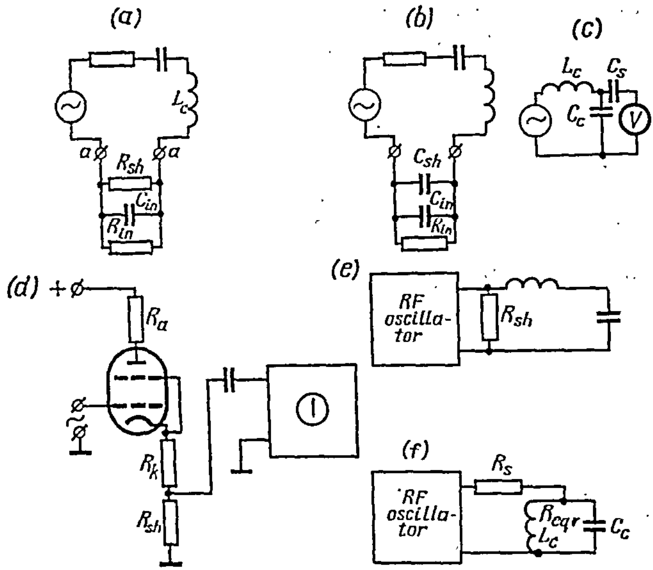

Fig. 23. Shunting of instrument and connection of series resistor

(a) active shunt; (b) capacitive shunt; (c) connection of series capacitor; (d) use of active shunt when observing anode current of triode on oscillograph; (e) use of active shunt when supplying series oscillatory circuit; (f) use of series resistor when supplying parallel oscillatory circuit

The supply circuit of a series resonance circuit is shown in Fig. 23e. If the output resistance of the RF oscillator does not satisfy the inequality $R_{out} \ll R_{cir}$ (where R_{cir} is the resistance of the resonance circuit), the oscillator output is shunted by resistor R_{sh} which is determined from the inequality

$$R_{sh} \leqslant \frac{0.1\, R_{cir}\, R_{out}}{R_{out} - 0.1\, R_{cir}}$$

When this inequality is observed, the Q-factor of the circuit, on connection of the oscillator, does not change by more than 10 per cent. It should be borne in mind that shunting of the oscillator output may violate the calibration of its output voltage, so that it should not be relied upon without introducing the necessary corrections.

When a parallel resonance circuit is supplied by an oscillator with a low internal resistance, a series resistor (Fig. 23*f*) is connected. If the inequality $R_s \gg 10R_{eq}$, is observed, the resonance resistance of the parallel circuit R_{eq}, on connection of the oscillator with the series resistor R_s, will not change by more than 10 per cent. If the oscillator is connected to the circuit without a series resistor, the output resistance of the oscillator shunts the resonance circuit and the equivalent Q-factor and resonance resistance of the circuit decrease sharply.

When shunting the oscillator output, it must be ascertained that the oscillator has sufficient power to develop the required voltage across the shunt resistance. When including a series resistor, the oscillator should have such an output voltage that even with the inclusion of the series resistor the required voltage will fall across the circuit being supplied.

Use of voltage dividers. To reduce the coupling of the measuring instrument to the tested circuit use is made of resistive, capacitive, and compensated voltage dividers. When selecting the type of voltage divider, allowance should be made for the frequency range in which the input resistance of the measuring instrument is to be measured.

If within the given frequency range the input resistance of the measuring instrument can be regarded as purely ohmic, it is best to use a resistive voltage divider (Fig. 24*a*), and if it is capacitive, then use is made of a capacitive voltage divider (Fig. 24*b*).

In the general case the input resistance of the measuring instrument possesses a resistive-capacitive nature; at low frequencies it can be regarded as purely ohmic, and at high frequencies, when the resistance of the input capacity is much lower than the ohmic input resistance, as capacitive.

When measuring signal parameters throughout a broad frequency range, and, in particular, short-duration pulse signals, use is made of compensated voltage dividers which make it possible to obtain a constant division factor throughout a broad frequency range (Fig. 24*c*). At low frequencies the reactance of capacitors C_1 and C_2 is high, and the divider functions as a resistive divider, while at

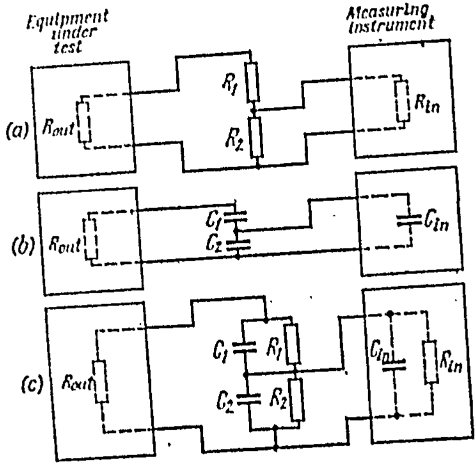

Fig. 24. Use of voltage dividers

(*a*) resistive; (*b*) capacitive; (*c*) compensated

high frequencies the reactance of capacitors C_1 and C_2 is much lower than the resistance of R_1 and R_2, and the divider functions as a capacitive divider. The divider networks C_1C_2 and R_2R_1 are calculated for the same division factor, therefore it remains constant at both high and low frequencies.

The uniformity of the frequency response is retained until there is a change in the input resistance of the measuring instrument due to an increase in dielectric loss. The input resistance of the divider should be high in comparison with the output resistance of the equipment under test.

Creation of actual operating conditions when adjusting separate units of systems. In batch and mass production it is usual to adjust and check the units of a system separately (Fig. 25). Let us examine two cases.

1. The unit under test B_1, which is a source of continuous or pulse signals, is loaded by unit B_2 which possesses input resistance R_{in} and input capacitance C_{in} (Fig. 25*a*).

In some cases standard unit B_2 is built into the test

bench which is intended for adjusting and checking unit B_1. In parallel to the line interconnecting the units is connected measuring instrument MI, for instance, a voltmeter, an oscillograph, or a frequency meter, the input resistance of which is R_{inst} and the input capacitance is C_{inst}.

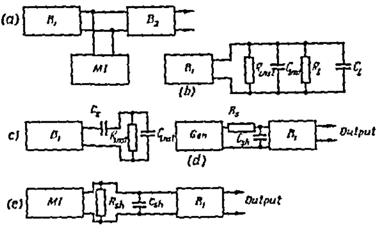

Fig. 25. Connection of measuring instruments in unit-by-unit adjustment

(a) unit B_1 loaded by unit B_2 of the system; (b) unit B_1 loaded by dummy load; (c) connection of series capacitor; (d) connection of series resistor; (e) connection of shunting resistor

Such connection is not always permissible because the unit under test is loaded not only by its actual load Z_{in}, but also by the input resistance of the instrument.

Often the unit being tested is loaded by a dummy load which contains parallel-connected resistor R_l and capacitor C_l. The load parameters are selected such that the total load of the unit under test, with allowance for the input resistance of the measuring instrument, equals input impedance Z_{in} of the unit which serves as a load for the tested unit B_1 in the actual circuit.

If $C_{inst} < C_{in}$ and $R_{inst} > R_{in}$ (Fig. 25*b*), the load parameters are determined from the equations

$$C_l = C_{in} - C_{inst}$$

$$R_l = \frac{R_{inst} R_{in}}{R_{inst} - R_{in}}.$$

One should avoid connecting measuring instruments whose $C_{inst} > C_{in}$ or $R_{inst} < R_{in}$. In certain cases, when $C_{inst} > C_{in}$ and $R_{inst} \gg \frac{1}{\omega C_{inst}}$, it is possible to connect in series with the instrument capacitor C_s (Fig. 25*c*), the value of which

$$C_s = \frac{C_{inst} C_{in}}{C_{inst} - C_{in}}$$

2. The unit under test B_1 has an input and an output (Fig. 25*d*, *e*). This may be an amplifier unit, a shaping circuit, or an oscillator with external excitation. As for the connection of the measuring instrument and the load to the output of unit B_1, all that was said above applies to this case too.

Let us consider ways of creating actual operating conditions for unit B_1, as regards its input.

In a number of cases the test bench for adjusting unit B_1 may include a standard preceding unit of the system, the output signal of which is used for adjusting and checking unit B_2. In this case, actual operating conditions as regards the input are retained, if no additional measuring instruments are connected, which significantly change the resistance between the conductors of the line connecting the units.

Usually the unit under test is supplied with a signal from a universal or a special generator, at whose output the same kind of signal as is applied to the input of unit B_1 in the actual circuit is produced.

When designing special oscillators intended for adjusting the given unit, provision is made for built-in measuring instruments and allowance is made for their effect on the output resistance of the oscillator, so that it is equal to the output resistance of the unit supplying unit B_1. If a universal oscillator with a variable output resistance is used, its output resistance, if this is possible, is set to the necessary value.

In general, the input conditions of the unit under test, including all additional elements, are maintained constant.

The output resistance of universal oscillators can usually be regarded as ohmic. Let us designate this resistance $R_{out.\,osc}$ and the output resistance of the unit supplying unit B_1 we shall regard as parallel-connected resistor $R_{out.unit}$ and capacitance $C_{out.\,unit}$. If $R_{out.\,osc} < R_{out.unit}$, it is necessary to connect in series with the output resistance of the oscillator series resistor $R_s = R_{out.unit} - R_{out.osc}$, and if $R_{out.osc} > R_{out.unit}$, it is necessary to connect in parallel to the oscillator output shunting resistor $R_{sh} = \frac{R_{out\,osc} R_{out.unit}}{R_{out.osc} - R_{out.unit}}$. Capacitor C_{sh} is selected equal to $C_{out.unit}$ and is connected as shown in Fig. 25*d*, *e*.

Matching impedance when connecting measuring instruments to SHF channels. In the SHF range energy transmission lines are made in the form of coaxial or waveguide lines possessing the wave impedance ρ. When the line is loaded by a resistance equal to ρ, its input impedance is also equal to ρ for any length of the line without loss. This makes it possible to series-connect into the line sections of waveguide or coaxial lines (such as those in the line of the channel under test) without changing the input impedance and the operating conditions of the channel.

The principal measuring instruments used for investigating SHF circuits are power meters, slotted lines, and oscillators. Feed-through power meters and slotted lines are connected in series into the SHF channel at any place between the oscillator and the load. Not to introduce significant changes in the operating conditions of the transmission line it is necessary:

that the inclusion of measuring instruments in the channel should not cause reflections. For this the wave impedance of the instrument line should be equal to that of the energy transmission line, and at the places where they join, the connectors used should not introduce any reflections;

that the elements of the measuring instrument, which serve to tap part of the energy (probes of slotted line, openings of directional coupler), should not introduce significant changes in the electromagnetic field of the waveguide or coaxial line, i.e., the coupling between the measuring part of the instrument and the channel under investigation should be minimum. But in order to obtain nevertheless

sufficiently large readings of the indicating instrument, it is necessary to employ sensitive pointer meters and, if necessary, to first amplify the detected signal. In this case it is convenient to supply the SHF channel with modulated voltage, so as to use an audio amplifier for amplifying the detected signal.

An output power meter is connected instead of the load of the line to be tested. The input impedance of the power meter should be equal to the wave impedance of the line, and the connection of the instrument to the line should not introduce reflections. Under these conditions the output power meter functions as a matched load of the line and consumes the same power as will be supplied into any other matched load, for example, a transmitter antenna.

The input of the SHF channel being tested is supplied with voltage from a generator. The generator supplies maximum power into the line at a definite relationship between its output impedance and the input impedance of the SHF channel, namely under the condition when $R_{out}=R_{in.l}$ and $X_{out}=-X_{in.l}$ (where X_{out} and $X_{in.l}$ are the output reactance of the generator and the input reactance of the line, respectively).

To observe the equality $X_{out}=-X_{in.l}$, it is necessary to load the channel under test by an impedance possessing a reactive component, but in this case the input impedance of the line will depend on its length, and the inclusion of series-connected measuring instruments or other sections of the line will change the input impedance of the transmission line.

Measuring generators usually possess an output impedance equal to the wave impedance of the transmission line, and therefore they supply the maximum power when the line under test is loaded by its wave resistance. The outputs of generators are provided with attenuators of either the resistive or cut off types, with the aid of which the required level of output power is set.

In some types of measuring SHF generators the output power and the frequency vary significantly with variation in the load (for instance, when shifting the probe of the slotted line), if the attenuator is fully advanced, i.e., its attenuation of the signal is equal to zero. In these cases

it is necessary to constantly adjust the frequency and the output power (which is very inconvenient), or to introduce such attenuation with the aid of the attenuator, when the effect of the load on the generator is sufficiently small.

3.4. METHODS OF MEASURING PARAMETERS

Whether a given parameter conforms to the required value can be determined by direct measurement with the aid of a measuring instrument, by an indirect method, by the methods of comparison or substitution, etc.

In the *direct measurement method* a certain parameter is measured with the aid of appropriate measuring instruments (for example, the output voltage of an amplifier with a voltmeter, the load current with an ammeter, frequency with a frequency meter, phase angle with a phase meter).

In the *indirect method* the parameter is not measured directly. Instead, other values are determined, which are bound to it by definite functional relationships.

In the *comparison method* the parameter of the equipment being checked is compared to that of the equipment accepted as the standard.

In the *substitution method* the unit being checked is connected into the standard equipment and its operation is judged by the output parameters of the standard equipment.

Various characteristics can be measured by two methods: point by point or with the aid of cathode ray curve tracers. When measuring the characteristic $y=f(x)$ point by point, it is necessary to set a definite value of x and to measure the corresponding values of y, maintaining other conditions equal. On obtaining a number of values of x_1, y_1, they are plotted on a graph, and the points are connected by a curved line. A cathode-ray curve tracer makes it possible to obtain the required characteristic $y=f(x)$ directly as a curve on the screen of a cathode-ray tube.

Direct measurement of parameters. When a measuring instrument is connected to the equipment under test, a new circuit is obtained, the parameters of which differ more or less from the parameters of the circuit before con-

nection of the instrument. As a result, the currents and voltages change, and the parameter under test is not measured precisely, even despite absolute accuracy of the measuring instrument. Another source of additional errors is the fact that the magnitude being measured is not fully applied to the input of the measuring instrument. This is usually due to the presence of parasitic coupling and the effect of the circuitry inductances and capacitances of the measuring instrument.

Figure 26 shows examples illustrating the effect of parasitic coupling. Only part of current I being measured (Fig. 26*a*) flows through ammeter A because current I'

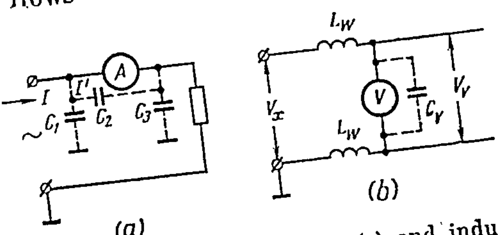

Fig. 26. Effect of parasitic capacitances (*a*) and inductances (*b*) of measuring instruments

flows through parasitic capacitances C_1, C_2, C_3. Only part of the measured voltage V_x (Fig. 26*b*) is applied to the voltmeter, because there is a voltage drop across the inductance of connecting wires L_w. With an increase in internal capacitance C_v of the voltmeter, voltage V_v dropping across the voltmeter decreases.

Measuring instruments that are connected in series wit the circuit under test should be inserted at such a poi where the potential with respect to the chassis is zero minimal. Instruments for measuring the d.c. component a current are connected to that circuit where there is a.c. component of the current.

Figure 27*a* shows an example of incorrect connection instrument A_1 for measuring the d.c. component of the g current, instrument A_2 for measuring the d.c. compon of the anode current, and instrument A_3 for measuring current in the tank circuit. Instruments A_1 and A_2

a.c. components, thus producing a reaction in the grid and anode currents. In addition, they are connected in high-potential points of the circuit, and their parasitic capacitances with respect to the chassis produce an additional reaction. Instrument A_3 passes the d.c. component of the anode current, and at the same time part of the measured current is bypassed by the parasitic capacitances of the instrument.

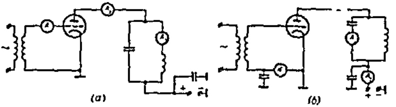

Fig. 27. Connection of measuring instruments
(a) wrong; (b) correct

Figure 27*b* shows the correct ways of connecting measuring instruments.

The inherent frequency of the measuring circuit must be many times higher than the working frequency of the circuit being tested, otherwise resonance phenomena may occur in the measuring circuit, and the errors in measuring the parameter may be very great.

Due to the parasitic couplings in the connecting wires of the measuring circuit, signals that were not there before the measuring circuit was connected may develop in the circuit under test. This is illustrated by the example shown in Fig. 28. Connecting wire *bb'* is coupled to wire *aa'* via parasitic capacitance C_{par}. As seen from the diagram, connected in parallel to the secondary winding of the transformer is a voltage divider consisting of capacitance C_{par} and the equivalent impedance $Z_{g.k}$ of the grid-cathode section of the amplifier.

A parasitic signal of 50 hertzes will be applied to the grid of the amplifier valve; the magnitude of it will depend on the ratio of the reactance of parasitic capacitance C_{par} to the equivalent impedance between points *b'* and *c*.

When setting up a measuring circuit, special care should be taken that parasitic couplings do not arise between its elements, for example, between the input and output of an amplifier. The presence of such couplings may cause self-excitation of the amplifier or a sharp change in its parameters. In all cases an attempt should be made to shorten connecting wires and to use diode heads.

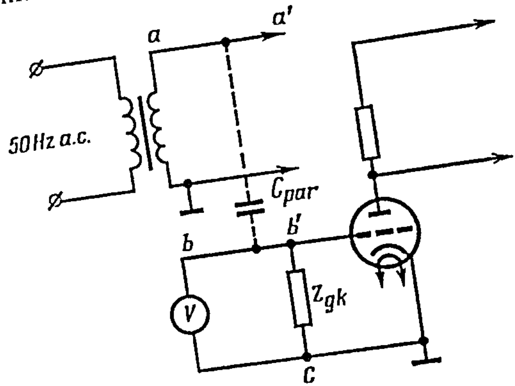

Fig. 28. Appearance of parasitic signal on connection of measuring instrument

The input or output of a measuring instrument may be balanced or not. When the input (or output) is not balanced, one of the input (or output) leads of the instrument is at zero potential with respect to the chassis. When an instrument with a balanced input (output) is connected to unbalanced points of the circuit under test, the readings of the instrument cannot be correct.

Figure 29*a* shows that when audio oscillator *AO* havi[ng] a balanced output is connected to equipment *Eq* with an u[n]balanced input, half of its output winding will be short-c[ir]cuited, if the chassis of the instrument and the equipme[nt] are connected together, or partially short-circuited by [pa]rasitic capacitance C_{par} between the chassis of the au[dio] oscillator and the equipment. Capacitance C_{par} is [not] constant. It depends on the relative positioning of the

strument and the equipment and on the connection of other devices which are located on the work place.

Similar results are obtained when the parameters of a balanced circuit are measured by an instrument with an unbalanced input. The anode of valve V2 (Fig. 29*b*) will be short-circuited to the chassis if the chassis of the amplifier and the voltmeter are connected together, or resis-

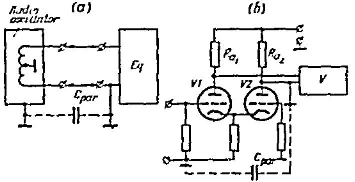

Fig. 29. Examples of wrong connection of instruments with balanced and unbalanced output (input)

(*a*) oscillator with balanced output supplying equipment with unbalanced input; (*b*) voltmeter with unbalanced input measuring output voltage of amplifier with balanced output

tor R_{a_1} will be shunted by parasitic capacitance C_{par}.

Thus, *it is necessary to choose an instrument* with a balanced input (output) for connection to balanced points of a circuit and instruments with an unbalanced input (output) for connection to two points of a circuit, one of which is at chassis potential. If appropriate instruments are not available, use should be made of balancing devices, *for example, balancing transformers*.

Connection of instruments should not form coupling circuits between the input and output of amplifiers. Figure 30 *shows an example of incorrect connection of instruments*. The current in wire *aa'* flows through the amplifier input, and a feedback voltage develops across wire *ab*.

Indirect methods of measurement. In indirect methods of measurement the parameter to be determined is found

by calculation after measuring other magnitudes. Since the results of the primary measurements may possess various degrees of accuracy, the resultant evaluation of the measurements should also be determined by calculation.

Let us examine several typical cases.

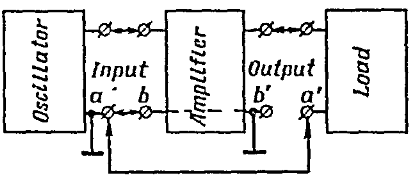

Fig. 30. Development of parasitic coupling between input and output circuits with wrong connection of instruments

1. Parameter x which we are interested in is equal to the algebraic sum of two measured values A_1 and A_2. The root-mean-square error in measurement of parameter x is determined by the expression

$$\sigma_x = \sqrt{\sigma_1^2 + \sigma_2^2}$$

where σ_1 and σ_2 are the root-mean-square errors in measuring magnitudes A_1 and A_2.

2. Parameter x which we are interested in is equal to the difference between the measured magnitudes A_1 and A_2, i.e., $x=A_1-A_2$. Such measuring schemes should be avoided, because at low values of the difference A_1-A_2 the relative measurement error γ of the sought magnitude x may be very great, as seen from the expression

$$\gamma = \frac{\sqrt{\sigma_1^2+\sigma_2^2}}{A_1 - A_2}$$

3. Parameter x which we are interested in is equal to the product of the measured magnitudes A_1 and A_2:

$$x = A_1 A_2$$

4. Parameter x which we are interested in is equal to the ratio of the measured magnitudes A_1 and A_2:

$$x = \frac{A_1}{A_2}$$

The relative measurement error γ of parameter x is determined for the third and fourth cases by the expression

$$\gamma = \sqrt{\gamma_1^2 + \gamma_2^2}$$

where γ_1 and γ_2 are the relative errors in measurement of A_1 and A_2.

Under production conditions any calculations are highly undesirable, for they reduce productivity, require more highly skilled workers, and serve as an additional source of errors. As a rule, it is possible to exclude calculations and obtain a direct reading of the parameter being measured on the scale of an instrument. Let us suppose that magnitude x can be determined by measuring other magnitudes y and z. If, with the aid of an indicator and an appropriate control, a definite value of y is set, the scale of the instrument measuring z can be calibrated in values of x.

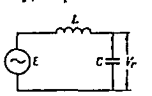

Fig. 31. Measuring Q-factor of tuned circuit

For example, the Q-factor of circuit LC (Fig. 31)

$$Q = V_r / \mathcal{E}$$

where V_r = voltage across the capacitor at resonance
$\mathcal{E}$ = e.m.f. of the supply source

By maintaining magnitude $\mathcal{E}$ constant, it is possible to calibrate the voltmeter in values of Q.

The resonance frequency $f_0 = \frac{1}{2\pi\sqrt{LC}}$. With a constant value of L the dial of variable capacitor C can be calibrated in values of f_0.

Comparison method. In the comparison method the parameters of the circuit under test are compared to those of another circuit of the same type, which has first been checked and accepted as a standard

The inputs of the standard and the tested circuits are supplied with one and the same signal. The output parameters of the standard and the tested equipment are measured with one and the same measuring device. In the simplest case the measuring device is switched manually or automatically. The difference between the readings obtained on switching the equipment serves as an indication of the departure of the parameter of the equipment under test from the permissible value.

Higher productivity can be achieved by the use of special comparison circuits. The input of such a circuit is supplied with signals from the outputs of the standard and tested equipment, and the output-signal parameter of the circuit is proportional to the difference between the output parameters. The scale of the measuring instrument connected to the output of the comparison circuit can be marked beforehand with a sector corresponding to the permissible difference.

If the amplitudes of the output signals are compared, it is possible to employ an amplitude comparison circuit (Fig. 32). The output voltage of the standard and tested equipment is detected by amplitude detectors (diodes D_1 and D_2). The voltmeter measures the voltage difference across the detector loads.

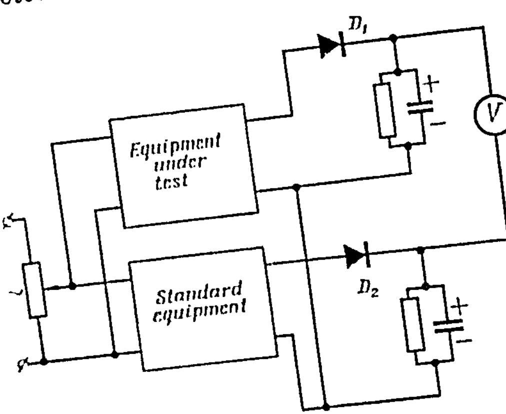

Fig. 32. Amplitude comparison circuit

When comparing the phases of signals, use can be made phase-sensitive voltmeters. For comparing frequencies e beat method is used, i.e., the differential frequency is btained with the aid of a detector and a filter (Fig. 33).

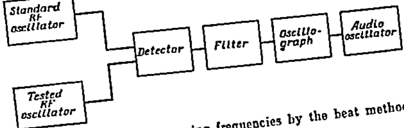

Fig. 33. Hookup for comparing frequencies by the beat method

Voltage of the differential frequency between the generators, separated out by the filter, is applied to the vertical deflection plates of an oscillograph, while voltage from an audio oscillator is applied to the horizontal deflection plates. By varying the frequency of the audio oscillator, it is possible to obtain an ellipse on the screen. In this case the differential frequency between the generators is equal to the frequency of the audio oscillator. The permissible frequency difference can be marked on the dial of the audio oscillator in the form of a coloured sector, for example.

When comparing resistances, it is possible to use bridg methods. Higher productivity is achieved by using th unbalanced bridge method (Fig. 34). The permissible di ference is marked on the scale of a valve voltmeter The rated reading can be corrected periodically with th aid of variable resistor R_0 by switching in standard in pedance Z_0 with the aid of switch Sw. When Z_x is switch in, the voltmeter reading should be within the perm sible values.

Substitution method. In the substitution method equipment to be checked is connected instead of the st dard equipment of the same kind. In such substitution output parameters of the standard equipment serve a

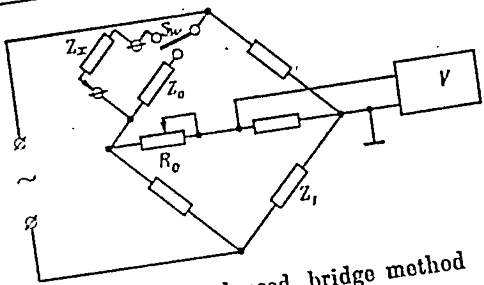

Fig. 34. Unbalanced bridge method

basis for judging whether the equipment being checked conforms to the permissible. This method can be used for checking delay lines of pulse generators, receiver intermediate frequency amplifiers, transmitter modulators, and other circuits. For increasing productivity, the range of permissible values is marked on the scale of the measuring instrument.

3.5. MEASURING CHARACTERISTICS WITH CATHODE-RAY CURVE TRACERS

Let us examine the operating principle of cathode-ray curve tracers, devices designed for observing and investigating the characteristics of radio circuits.

Cathode-ray curve tracers produce on the screen of a cathode-ray tube the frequency, amplitude, or other characteristic of a radio circuit, for the plotting of which on paper, on the basis of experimentally measured points, i[t] would require a lot of time. For instance, to plot the frequenc[y] characteristic of an amplifier it is necessary:

to connect an oscillator to the input of the amplifier an[d] a voltmeter to its output;

to vary by steps the frequency of the oscillator, mai[n]taining its output voltage constant, and to record simult[a]neously the frequency and voltage at the amplifier outp[ut];

to plot the frequency characteristic on paper on the [ba]sis of the measurements obtained.

Suppose the resultant characteristic does not meet [the] requirements of the specifications. Then it is necessary

introduce the appropriate modifications into the amplifier circuit and to repeat the process all over again.

The use of cathode-ray curve tracers has enormously increased the productivity of adjusters, that is why they are so widely used. Among the most widely used cathode-ray curve tracers are those that measure frequency response, *transient response*, the characteristics of vacuum valves and semiconductor devices, magnitization.

Circuits similar to those used in cathode-ray curve tracers are often used in various testing installations; they are built-in forming an integral part and ensure high productivity.

For all the diversity of cathode-ray curve tracers, they have a common operating principle which forms the basis for obtaining the functional dependence $y=f(x)$.

To obtain on the screen of a cathode-ray tube any functional dependence $y=f(x)$, it is necessary to assemble the circuit so that the horizontal sweep of the ray will be proportional to argument x. If simultaneously the vertical deflection plates are supplied with voltage V_y which is proportional to function y, the curve of this function will appear on the screen. The voltages applied to the deflection plates must be directly proportional to the values of y and x, respectively, not to distort the representation of the function.

Thus, if the deflection along the x axis is proportional to magnetic field strength H, and the deflection along y, to the magnetic flux density, a representation of the magnetization curve can be obtained on the tube screen.

If x is proportional to the frequency and y, to the amplitude of an amplifier output voltage, a frequency response curve can be obtained on the screen. With $y=f(xz)$ it is possible to obtain on the screen a family of curves of $y=f(x)$ for various values of z. For this it is necessary to change in jumps the value of z during the flyback of the ray.

Cathode-ray curve tracers employ various calibrators which make it possible to superimpose scale marks on the curve. These marks help determine the value of one or another parameter. For example, in frequency response tracers there are circuits for obtaining frequency scale marks on the screen. In order to increase productivity, tolerance li-

mits are marked on a transparent face plate placed over the screen, or use is made of a comparison method, when, with the aid of an electron switch, the standard curve and that of the equipment being checked are simultaneously presented on the screen.

We have examined the basic methods of measuring the parameters and characteristics of radio equipment. In conclusion it is necessary to deal with the problems that develop when it is necessary to change the type of instrument, the measuring circuit, or the supply source.

3.6. CHANGES IN TESTING PROCEDURE

In case of any change in the supply source (type of dynamomotor, converter, etc.), as well as when changing the type of the measuring instrument used in testing, the measuring procedure or the hookup of the measuring circuit, great care should be taken to avoid any mistakes which may have grave consequences.

It should be borne in mind that the readings of many measuring instruments, voltmeters for example, depend to a great extent on the shape of the voltage.

The equipment should be designed and tested with the aid of a definite primary supply source and definite types of measuring instruments. The same instruments should be used in evolving and determining tolerances. Errors connected with current shape and certain other sources of instrument errors are not significant as long as the testing procedure, the type of supply source, and the type of measuring instruments remain the same. In the event of a change in the type of supply source or the type of measuring instrument, it may happen that the equipment that has passed the test in all parameters proves inoperative under service conditions.

To exclude errors connected with a change in the type of measuring instruments, supply sources, or testing procedure, it is necessary to check part of the equipment with both the new and the old measuring instruments, supply source or according to both the new and the old procedures. Comparison of the test results will show whether the old limits for the equipment parameters may be retained or they should be changed.

3.7. MECHANIZATION AND AUTOMATION OF TESTING

The fact that radioelectronic devices are becoming ever more complex has already been mentioned. Let us imagine for instance, the functions of the radioelectronic equipment of a spaceship. It must monitor the coordinates of the spaceship, the amount of fuel, the presence and intensity of streams of various particles of matter, temperature and pressure, the frequency and amplitude of vibration in various parts of the spaceship; maintain radio communications with Earth and transmit television pictures to Earth; monitor the vital functions of organisms and plants located on board the spaceship; control the operation of engines, etc.

The radio equipment of aircraft provides constant radio communication with Earth, measurement of altitude, blind landing, automatic control of the craft, monitoring of the operation of engines, and numerous other devices maintaining normal conditions within the craft, radar surveillance of the surroundings, etc.

Monitoring of manufacturing process is provided by complex circuits including tens of thousands of various components. One of the important conditions for increasing the reliability of such systems is monitoring of the parameters of components, assemblies, and devices. The wide use of manual labour increases greatly the cost of adjusting, checking, and testing radioelectronic equipment. The important task is to reduce the labour required for adjustment, checking, and testing and to simultaneously improve the quality of testing operations.

To understand better the ways of reducing the labour required for such work, it is necessary to examine in greater detail the operations which an adjuster and checker must perform in the absence of mechanization and automation:

connection of supply sources and measuring instruments to the equipment to be adjusted or checked;

measurements which help check whether assembly and wiring have been made correctly, that there are no faulty parts or assemblies, or other defects that disturb operation;

fault finding based on an analysis of measurements;

elimination of discovered faults;

measurement of the parameters of the equipment being adjusted;

analysis of the results of measurements and determination of methods for obtaining the required parameters;

variation or replacement of certain circuit components and the obtainment of the required characteristics and parameters;

testing for conformity with the requirements of the specifications.

The above adjustment operations may be performed in different order and repeated many times until the requirements of the given specifications are met.

The work of an inspector who only checks and tests the radioelectronic equipment electrically includes:

checking of parameters of the equipment that has been adjusted and forwarded for acceptance;

detection of equipment that does not satisfy the requirements;

analysis of the causes of rejects (in the case of active checking which provides for elaborating recommendations for methods of reducing rejects).

The enumerated operations in the work of an adjuster and a checker consume different labour. Most of the time is consumed by measurements and their analysis. Operations on eliminating faults, when they have already been found, or on alignment and adjustment, when the methods of adjusting the given parameter of the equipment are already known, take up little time and are absent altogether in testing.

Let us consider the basic methods for reducing the labour required for measurements. Let us suppose that the output voltage of a four-pole is measured under set conditions (Fig. 35). The adjuster must connect to the four-pole an oscillator, a frequency meter, voltmeter V_1 for measuring the input voltage and voltmeter V_2 for measuring the output voltage. He *must* measure the oscillator frequency with the frequency meter and, if it does not conform to that required, make the appropriate adjustment of the oscillator. Adjusting the output voltage of the oscillator, he sets the given voltage according to voltmeter V_1 and only after this does he take the reading of the four-pole output voltage.

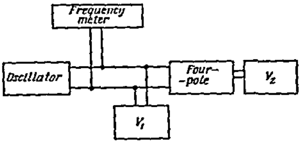

Fig. 35. Measuring output voltage of four-pole

If this measuring equipment is replaced by a combination instrument containing an oscillator, a frequency meter and both of the voltmeters required, and a convenient way of connecting the four-pole to this instrument is provided, the measuring time can be considerably reduced. Various cathode-ray curve tracers present a combination of instruments that considerably increases the productivity of an adjuster.

Replacement of indirect measurements by direct measurements is one of the most important ways of reducing measuring time.

In those cases when the precise value of a parameter need not be determined but it is only necessary to know whether it is within permissible limits, coloured sectors corresponding to the permissible limits of the parameter are marked on the scale. This simple method increases productivity and decreases fatigue on the part of the adjuster. For signalling that a parameter is not within permissible limits, use is made of signal lamps or bells connected to the automatic checking circuit which develops an actuating signal.

In checking hookups, the operating conditions of valves, transistors, and other components, in measuring the parameters of complex multichannel circuits use is made of electromechanical switches which automatically switch supply sources, the leads of the equipment under test, and the measuring instruments.

Elimination of numerous registrations of the results of measurement from the duties of the operator and the repre-

sentation of various characteristics are an important way of automatic testing operations. In automatic recording, the results of measurement may be obtained in the form of numerals and signs on paper tape, in the form of photographic characteristics on which calibration marks are superimposed, etc.

Full automation of measurements provides for:

the absence of manual adjustment and tuning of the measuring equipment (switching of measuring ranges is either not done at all or done automatically);

automatic recording of results of measurement;

prolonged storage of results of measurement and possibility for reproducing them at any time (sometimes provision is made for supplying them into a computer for mathematical processing).

Review Questions

1. What are the basic documents used by an adjuster of radio equipment?
2. What requirements must facilities of a work place of an adjuster meet?
3. What are the advantages of centralized supply of test signals and supply voltages to the work places of adjusters?
4. How are actual operating conditions created for units of equipment during their adjustment?
5. What methods of measuring the electrical parameters of radio equipment exist?
6. What operations are performed by an adjuster when he checks the parameters of radio equipment?

CHAPTER IV

Checking Operating Capacity

4.1. CHECKING CONNECTIONS

Before switching on the equipment for adjustment, it is *necessary to make sure that its components have been connected* properly. Mistakes of the hookup man not discovered before the equipment is switched on may cause short-circuits, damage to expensive assemblies and high-current components or breakdown of dielectrics by high voltage.

Visual inspection. In the case of rigid wiring (with short single-strand wire), the correctness of connections can be checked visually by comparison to a wiring diagram or to a sample. It should be borne in mind that in radio frequency stages not only must the connections be made correctly, but also *significant is the mutual positioning of capacitors*, resistors, and other radio components with respect to the chassis, as well as the arrangement of the wires. For example, variation in the distance from a capacitor to the chassis varies the capacitance of the given circuit with respect to earth, bringing together the wires and components of grid and anode circuits increases the feedback between them.

In visual inspection it is necessary to check all the connections made to the chassis. Absence or poor quality of these connections may cause serious violation of operating capacity: the appearance of an a.c. hum, self-excitation of oscillators, etc. In some cases even the place where a connection is made to the chassis is important. Therefore, displacement of the earthing point must not be allowed, even though this does not disagree with the circuit diagram.

Checking with the aid of a continuity tester. When checking whether connections have been correctly made in the case of bunched wiring, visual inspection is apt to allow mistakes, especially if the bunch contains wires of the same colour. The same applies to multi-conductor cables that are used either inside units or for interconnection of them. In piece and small-batch production the connections of bunched wires and cables are checked with a continuity tester. The circuit of a continuity tester is shown in Fig. 36.

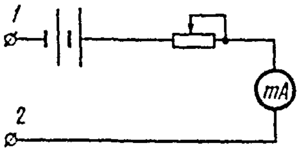

Fig. 36. Circuit of continuity tester

When the circuit is made through the circuit being checked, the milliammeter gives the same reading as in case of contacts *1-2* being short-circuited. If the circuit is broken, the milliammeter gives no reading.

The manufacturing process for checking whether connections have been made correctly must be well thought out. It is necessary to select such a checking procedure that ensures the least waste of time and the highest reliability. For example, if a number of wires form a series circuit, it is possible to check the whole circuit at once and not each wire separately. Only if an open is discovered in the circuit, does it become necessary to check each connection separately. One should see to it that the circuit being checked is not shunted by a low resistance.

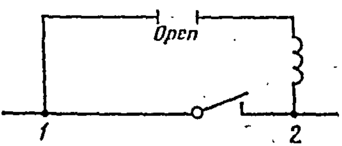

Fig. 37. Checking correctness of connections

Circuit *1-2* (Fig. 37) is shunted by the closed contacts of the relay so that the break in this circuit is not brought to light while checking.

The break in the heater circuit shown in Fig. 38 cannot be discovered by the continuity tester because the heater circuit is shunted by the low resistance of the transformer secondary winding.

When checking circuits connected with an electromechanical relay, it is often necessary to break the relay contacts by placing an insulating gasket between them. Otherwise certain circuits can be shunted by the low resistance of windings or directly by the contacts. For reducing checking time and excluding shunting circuits it may prove useful to set switches and other switching devices in definite positions.

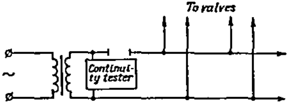

Fig. 38. Checking heater circuits

The correctness of connections is checked against connection tables or technological charts. For increasing productivity in checking correctness of connections, wide use is made of automatic and semiautomatic devices.

Semiautomatic device for checking correctness of connections. A simple semiautomatic device for checking cables can be made in the following way. A cable is connected to the semiautomatic installation with the aid of connectors Con_1 and Con_2 (Fig. 39*a*). One of the connectors of the semiautomatic device has a contactor which connects electrically the cable ends. The lead of the contactor is connected to a d.c. supply source which is connected in its turn to the brush of a step-by-step switch. The second connector is connected to the contacts of the step-by-step switch, with a signal lamp included in series in each line connecting the cable lead and the switch contact.

The step-by-step switch (Fig. 39*b*) is controlled by a pulse generator. The generator pulses are fed to the winding of electromagnet *2* at a frequency of 1 hertz. Each pulse causes rachet wheel *4* to turn by one tooth, and at the same time brush *1* shifts to the next contact of commutator *6*, connecting the corresponding circuit. If the circuit is in order, the signal lamp lights up.

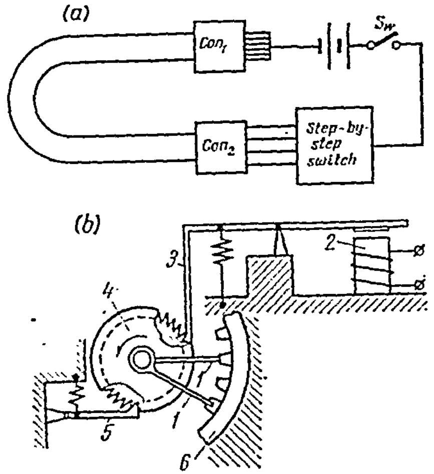

Fig. 39. Semiautomatic device for checking cables
(a) hookup; (b) design of step-by-step switch

The inconvenience of the described semiautomatic device is that it is necessary to keep a constant watch on the operation of the installation, because on crossing over to the next contact of the commutator, the signal lamp goes out with the circuit in order, and it is possible to miss the passage of the brush over a commutator contact connected to a faulty circuit.

In advanced semiautomatic installations, the supply source circuit includes a relay that breaks the supply circuit of the electromagnet winding, when the step-by-step switch passes over a faulty circuit.

4.2. RESISTANCE AND VOLTAGE CHECKING OF CIRCUITS. CHECK CHARTS

Comprehensive checking of components. We have discussed checking of the correctness of connections, that makes it possible to discover breaks in wires and mistakes in connecting them. During assembly other types of mistakes are possible, for example, the installation of faulty components

or components whose ratings do not correspond to the requirements of the circuit.

Many resistors and capacitors having different ratings are designed alike and if the assembler is not sufficiently attentive, they can be easily mixed up. Wrong soldering conditions can cause the failure of semiconductor diodes and triodes. Damage may be inflicted on wire insulation with a soldering iron, when soldering closely located leads of components and the ends of wires.

Checking of each circuit component would take up a lot of time. Higher productivity in checking the correctness of assembly of components in radio equipment can be obtained if each measurement checks the correctness of a group of components. For this, those check (test) points are determined that make it possible with a minimum of measurements to check the maximum number of components.

Checking against resistance and voltage charts. There are two ways of making comprehensive checks of components:

with the supply source disconnected the resistance is measured between check points and the chassis or the positive terminal of the anode supply circuit;

with the supply source connected the voltages are measured between check points and the equipment chassis.

In the first method the resistance is measured with an ohmmeter or a multimeter and checked against a resistance chart (see Fig. 16).

The advantage of this method is that the circuitry is checked with the supply source disconnected. Therefore, there is no danger of damaging any components due to mistakes in the circuitry.

In the second method voltage is supplied to the circuit being checked from a supply source known to be good. The voltage between the check points and the chassis is measured with a voltmeter or a multimeter. The results of the measurements are checked against a voltage chart (see Fig. 17). In this method certain components of the supply source or of the circuit being checked may fail to operate. But the second method has great advantages compared to the first method. The correct operating conditions of such components as valves and transistors can be checked only

under actual working conditions, because their parameters depend on the voltages applied to their electrodes. The conjunction of these voltages determines the operating conditions of these devices. The operating conditions of thermistors, barretters, and other non-linear components can also be checked with the supply source switched on, i.e., under voltage. The causes of abnormal operating conditions of valves, transistors, and other non-linear components may be defects in the components themselves and mistakes in the circuits connected to them.

In determining the reasons for abnormal operating conditions, it is often necessary to cross over to checking against the resistance chart to avoid damaging overloaded components. One must be sure there are no short-circuits in the anode and screen-grid supply circuits, and also no galvanic connection between circuits which should be insulated from each other. Then a consecutive measurement of the resistance at the check points is made and the results are compared to the resistance chart. If no great departures are discovered, the reason for abnormal operating conditions should be sought in the components whose parameters depend on the magnitude of their current: in this case, they are replaced in turn by components known to be good.

Checking of circuitry and operating conditions with the aid of voltage and resistance charts is widely used in conditions of small-batch production. The inclusion of such charts in the operating instructions of radio equipment greatly help those people who have to repair the equipment.

Design of automatic and semiautomatic installations for comprehensive checking of components. Under the conditions of large-batch production, use is made of various automatic and semiautomatic stands for checking resistances and voltages at check points.

The automatic checking stand is connected to the equipment to be checked by cables terminating in connectors. In this case use is made both of the connectors incorporated in the equipment and of special checking receptacles. In circuits employing valves, the stand and the equipment are often connected via the valveholders of the equipment, from which the valves have been removed. The valves are installed in the valveholders of the stand, and they become

connected to the corresponding circuits of the equipment via connecting cables and measuring instruments. These measuring instruments make it possible to simultaneously observe the voltages of several electronic valves and the voltages in groups of check points.

Such a system of checking operating conditions is only suitable for audio frequency circuits. On radio frequencies the parasitic inductance and capacitance of the connecting cables can sharply violate the operating conditions of stages.

Despite the wide variety of radioelectronic equipment and, consequently, of installations for automatic checking of circuitry and operating conditions, it is possible to discover a commonness of the operating principles of such installations which spring, first of all, from the fact that the installations have similar functions: checking of resistance or voltage at check points. Consequently, all the installations have switches that consecutively connect the check points to the measuring circuit. Secondly, the results of the given measurements must be compared to the rated values, therefore the automatic stand must include a comparison circuit. Thirdly, the installations must have a signalling system warning of impermissible departures of resistance or voltage from rated value.

A simplified block diagram of a tester for checking circuitry and operating conditions is shown in Fig. 40*a*.

Let us consider a case of resistance checking. The switch consecutively connects the check points to the comparison circuit (Fig. 40*b*), for example, to a d.c. bridge, one arm of which contains standard resistor R, and the other, resistor being tested R_{test}. The bridge arms are selected so that when tested resistor R_{test} and standard resistor R are equal, the bridge is balanced, i.e.,

$$R_1 R = R_2 R_{test}$$

Supply voltage is applied to one diagonal of the bridge. In the case of inequality $R_{test} \neq R$, a voltage directly proportional to the difference between R and R_{test} appears across the second diagonal.

The voltage is supplied to an indicator. The indicator circuit ensures that the relay operates when the value of

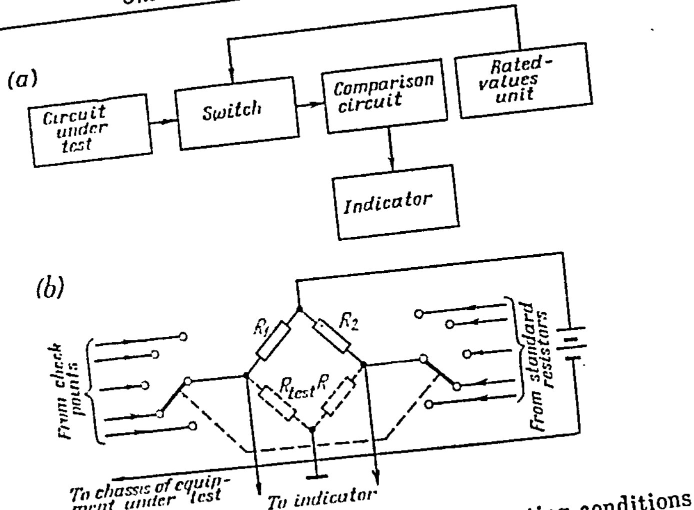

Fig. 40. Tester for checking circuitry and operating conditions
(a) block diagram of device; (b) comparison circuit

resistor R_{test} departs beyond the permissible limits, causing a lamp to light up or a meter to deflect beyond the permissible value marked on the meter scale in the form of a coloured sector.

In automatic stands the unbalance is supplied to a stopping relay which operates when the value of resistor R_{test} departs beyond the permissible limits, causing the switch to stop in that position which corresponds to the faulty circuit.

For switching, wide use is made of step-by-step switches, the design of which was considered in Sec. 4.1.

4.3 METHODS OF FINDING FAULTS.

In the adjustment and repair of radio equipment considerable time is usually spent in finding the causes of faults. Thus, in the repair of radio equipment about 70 per cen of the time is spent in finding the fault and only 30 pe cent in selecting and replacing the faulty component. Espe cially much time is spent in finding faults under the cond

tions of experimental production, since in such cases the fault may be due not only to defects in production but also to mistakes in the designing of the equipment.

In large-batch and mass production the main causes of faults are defects in the production of equipment and its components, as well as defects that have arisen during transportation and storage of the standard parts and materials.

To find a fault means to find the component that has failed or a mistake in the assembly and wiring of the equipment. Modern radioelectronic circuits contain very many components so that rapid discovery of a fault requires high skill on the part of the adjuster, a sound knowledge of the circuit being adjusted, of the methods of checking it, as well as of effective methods of finding faults.

Faults. Their types and symptoms. Faults can be both mechanical and electrical.

Among *mechanical faults* are defects in systems of transmission from tuning controls to dials and control knobs, violated contacts in switches and coatings of insulating strips, defects in systems of mounting of components, etc.

Among *electrical faults* are defects in valves, transistors, resistors, capacitors, coils, and other radio components, as well as mistakes in connections between them and the chassis of the equipment.

In most cases the elimination of electrical faults requires the replacement or repair of components and circuits. Typical symptoms of such faults are:

breaks in circuits;

considerable increase in resistance;

considerable decrease in resistance;

short-circuits.

Fault finding procedures. There are various procedures for finding faults.

The intermediate measurements method in which the passage of the signal is checked from unit to unit and from stage to stage until the faulty unit and then the faulty stage is found.

The exclusion method in which the normal units (stages) are consecutively excluded from the search. Thus, if the input of an audio frequency amplifier is supplied with a signal from an audio oscillator and a sound of normal volume

is obtained at the output, the AF amplifier may be considered normal, and the fault should be sought in other parts of the receiver.

The method of replacement of individual components with ones known to be good is especially widely used in valve circuits. By consecutively replacing the valves in a faulty circuit with ones known to be good, it is possible to either find the faulty valve or to become convinced that there are no faulty valves.

The comparison circuit in which the results of testing the equipment which has failed are compared to those of the same kind of equipment known to be good.

External examination is a method that makes it possible to discover many mechanical and certain electrical faults, for example, burnt-out composition resistors and the breakage of wires.

Among the typical symptoms of faults that are discovered during external examination without the use of measuring instruments are the following:

absence of glowing of valve heaters, changes in the colour of resistors, abnormal operation of potentiometers, and other control components;

overheating of transformers, electrolytic capacitors, and valve anodes;

presence of characteristic smells caused by overheating of coatings, impregnating and other materials;

appearance of, or changes in, the sound of mechanical assemblies, transformers, and other components which in normal operation either do not emit any sound at all or omit a sound which differs greatly in volume or quality.

The utility of employing one or another method of fault finding depends on the circuit and design of the equipment being checked. However, there are certain recommendations for accelerating fault finding which may be used when working with radioelectronic circuits belonging to the following classification:

supply circuits, including rectifiers and devices for protecting them from overloads (fuses, protective relays, etc.);

functional circuits with consecutive passage of signals including amplifiers, generators, and other circuits in which the signal passes consecutively from stage to stage, without

branching off, and the failure of one of the stages leads to the absence of the signal at the input and output of all the following stages;

functional circuits with separation of signals, at the output of which the signal branches off and is fed to two or more channels; faults in such a circuit lead to the absence of signals simultaneously at the output of several channels;

functional circuits with several inputs and one output, which are subdivided into those operating on the coincidence principle (the signal appears at their output only when the input signals exist simultaneously) and those operating on the summation principle (an output signal appears even if there is only one signal at the input).

Most radioelectronic systems contain, in addition to the supply circuits, functional circuits with consecutive passage of signals. The component parts of these systems may be housed in different units. Therefore, unit-by-unit checking for the purpose of finding faults is not always the best, i.e., it is not always the shortest way for searching and finding the fault.

Thus, one supply unit may serve several functional units and a fault in any of them may violate the normal operation of the supply unit and, consequently, of all the other units. And again, the failure of one of the functional units may be the cause of failure of others, since they are connected via a common supply source. The order of checking the operation of various stages should not be chosen on the basis of their location in a unit or system but of their functional coupling with other stages. Such coupling may exist through the supply circuits or through the signal-passing circuits.

Fault finding in supply systems. In many cases fault finding is begun by checking whether the supply system is operating normally. The difficulty of finding faults in these systems is due to the fact that they are coupled to all the other functional systems. That is why in designing intricate radio equipment provision is usually made for systems of checking the operation of supply circuits and their protection from overloads. If dangerous overloads develop, the protective system operates (for example, a fuse blows out, a relay trips, etc.) disconnecting the primary supply source or other items of equipment. True, it remains un-

known whether the reason for the overload is in the supply circuit itself or those circuits that it supplies.

To answer this question it is necessary to disconnect all the loads. If after this the protection device does not operate, the fault must be sought not in the supply unit but in its load.

No-load operation of a supply source is not always permissible. For example, if a rectifier operates into a load of a capacitive nature, the output voltage increases with no load, that may cause breakdown of the filter capacitors. In this case the disconnected load should be replaced by an equivalent dummy load. If after disconnection of the load the protective circuit continues to operate, the fault must be sought in the supply unit.

Faults in supply units are found both on the basis of the readings of built-in meters and also with the aid of external measuring instruments. Among the typical measurements is measurement of the voltage at the input and the output of the supply circuit. The absence of voltage at the input of the supply circuit indicates a fault either in the protective circuit or in the primary supply circuit (wiring from the primary supply source), or that there is a violation of contacts in connectors or in the mains voltage selector switch.

In this case it is necessary to measure voltage consecutively with an a.c. voltmeter, beginning from the mains receptacle and so on to the primary winding of the power transformer. This makes it easy to discover the faulty component or section of the circuit.

The absence of voltage at the output of the supply circuit with normal voltage applied to its input may be the result of a short-circuit or an open in the circuit.

In the event of a short-circuit the protective circuit operates. Here it is necessary to disconnect the supply unit from the supply mains and carefully check with an ohmmeter and a resistance chart that all circuitry and component connections have been made correctly. Sometimes for locating the site of a short-circuit it is necessary to disconnect sections of the circuit in succession and check for the presence of the short-circuit in each section separately. A short may often be caused by the breakdown of a filter

capacitor. If on disconnecting a capacitor the protective circuit ceases to operate, this means that the capacitor has broken down or breaks down when voltage is applied to it. Such a capacitor should be replaced.

The absence of voltage at the output of a supply unit (with the transformer primary at normal voltage and provided that the protective circuit has not operated) indicates an open in the secondary circuit of the transformer or in the d.c. circuits. The fault is readily found with the aid of a voltmeter or an ohmmeter.

If the supply unit is in order, but on connection of the actual load the protective circuit operates, then the load must be connected step by step and not immediately (by units or groups of stages connected by a common supply line). While sound circuits are connected, the protective circuit will not operate. When the faulty part of the load is found, it can be divided in like manner into separate portions so as to localize the fault.

Finding a faulty stage in a consecutive functional circuit. When searching for a faulty stage use can be made of those measuring or indicating devices that are built into the equipment: voltmeter, speaker, oscillographic indicator, etc. On the other hand it is helpful to make use of signal sources if there are any in the equipment being checked.

Suppose that the functional circuit under consideration consists of a consecutive system of amplification and conversion of signals S_1-S_4 with voltmeter V at the output (Fig. 41*a*).

For checking such a circuit, one must have a measuring generator which develops at its output those signals which are supplied to the input of the given functional circuit or develop between its stages. In practice, this should be either a *measuring radio frequency generator* of the appropriate range, or a pulse generator, or an audio oscillator, all of them calibrated in frequency and output voltage.

If the functional circuit being checked contains several stages, it is possible to check the stages consecutively from the output to the input: apply a signal from the measuring generator to the input of the last stage and, having made sure that it is in order with the aid of the output indicator of the circuit, proceed to check the last stage but one, etc.

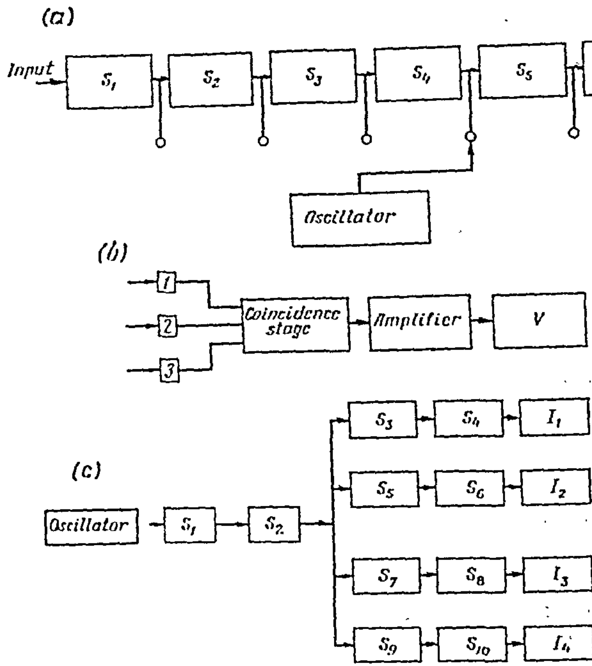

Fig. 41. Finding faulty stage

(a) in functional circuit with consecutively connected elements; (b) in functional circuit including coincidence stage; (c) in functional circuit with separation of signals

That stage will prove to be the faulty one, when application of a signal from the measuring generator to its input will produce no output voltage (no reading of the output indicator).

With a large number of stages the above fault finding method is not the best. To reduce fault-finding time it is possible, for example, to divide the complex circuit into two parts having the same number of stages. First the signal is applied from the measuring generator to that part of the circuit which contains the output voltage indicator. The presence of a normal output signal will indicate that the fault is located in the other part of the circuit. By si-

milar division of the faulty part into equal portions, it is possible to find rather quickly the faulty stage, even if the system is very complex.

A fault can be found still faster if the probability of failure of all the stages of the circuit is known. In this case division into parts is made not on the basis of the number of stages, but on the principle of equal probability of failure of those parts of the equipment into which it is divided in the course of searching for the fault.

The probability of failure of individual stages of the equipment may be determined on the basis of the statistics of failure of a large number of articles of the given type. If such data is contained in the adjustment instructions, recommendations should be made on the procedure of searching for faults with allowance for the probability of failure of the stages.

If the given functional system contains a built-in signal source and a small number of stages, it is useful to connect a voltmeter or other indicator to the stage outputs, beginning with the first one from the signal source.

With a large number of stages, the principle of division into parts should be applied. Checking should begin with that part of the circuit which contains the signal source.

Finding the faulty stage in a functional circuit with several channels. When finding faults in a functional circuit employing a coincidence circuit (Fig. 41*b*) with no signal at its output, it is necessary to check for the presence of signals at all the inputs *1*, *2*, *3* of the coincidence circuit. On discovering that one of these signals is absent, it is necessary to check the whole channel from the source of the given signal to the input of the coincidence circuit. In this case the same rules should be observed as were mentioned when dealing with the finding of faults in consecutive functional circuits. If there are signals at all inputs of the coincidence circuit and no output signal, it is necessary to look for the fault in the coincidence stage itself.

When finding faults in functional circuits with separation of signals (Fig. 41*c*), one can be governed by the following considerations. If there are no signals at all the output indicators I_1-I_4 or the actuating devices, *the fault should* be sought in signal separation stage S_2 itself, or in common

channel S_1. For example, if there is neither sound nor image in a television set, the fault must be sought in the common channel through which the television signal passes. The presence of a signal at the output of one of the channels usually signifies that the common channel is in order. In this case the fault should be sought in the channel beginning after signal separation, observing the rules for finding faults in a consecutive functional circuit.

Finding faults inside a stage. If the given stage includes a removable component such as an electronic valve, a thermistor, or a removable delay line, it is helpful to begin checking by replacing the removable components with others known to be good. This is especially important if the given components often fail. A test set of sound removable components is very helpful in finding faults, since the failure of removable components can be discovered very quickly.

If the replacement of removable components does not cause the equipment to operate normally, the operating conditions of valves and transistors should be checked with a voltmeter. Comparison of the measurements with a voltage chart usually makes it possible to draw a conclusion as to the nature of the fault and its possible causes. For example, the circuit of an amplifier stage is shown in Fig. 42*a*, and the voltage chart of this stage in Fig. 42*b*.

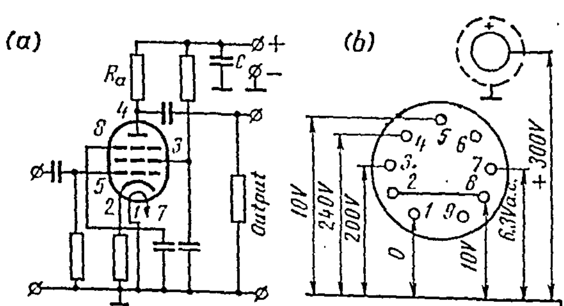

Fig. 42. Finding faults inside stage
(*a*) circuit of amplifier stage; (*b*) stage voltage check chart

Fig. 43. Short-circuit in heater circuit

Let us suppose that on measuring the anode voltage of the amplifier the voltmeter reads zero instead of 240 volts. The screen-grid voltage is +188 volts, and the cathode voltage, +8 volts, i.e., somewhat less than the normal (+10 volts). In this case the anode circuit of the stage is out of order, for example, there is a break or resistor R_a has failed. If the anode and screen-grid voltages are equal to that of the voltage source of +300 volts, then the reason for the failure should be sought in the control-grid or cathode circuit. Sharply reduced anode and screen-grid voltages may be due to short-circuiting of the cathode resistor or a broken-down capacitor. Other faults can also be found in a similar way.

In the case of faults that cause the protective circuit to operate and bring about obvious overloading of valves, resistors, or other components, it is necessary to switch off the supply source and to check the circuits against a resistance chart.

Under the conditions of experimental or small-batch production, voltage charts may not be available. In this case is convenient to use the method of comparing the operat- conditions of the faulty stage with those of the same kind stage known to be good. Comparison is made with the of an oscillograph, observing the a.c. voltage at the e points in the faulty and the sound stages.

hen finding faults in circuits including low resistances ected in parallel, it becomes difficult to localize a -circuit. For example, if there is a short in the heater its of valves (Fig. 43), it cannot be found with an ohm- , since the resistance of the heater and that of the trans-

former winding are low. A voltmeter will read zero on connection to any part of this circuit.

To localize the fault it is necessary to remove the valves, disconnect the heater circuit from the secondary winding of the transformer, and to make sure that there is voltage across the winding. Then only half of the heater circuit is connected, while the other half is disconnected by unsoldering one heater supply lead from the valveholder of the middle valve. If in this case the voltmeter again reads zero, the short-circuit is located in that part of the circuit that has remained connected to the transformer winding. If necessary, it is also possible to divide the remaining half of the faulty circuit in two to find more quickly that part where the short is located.

The fault is sought with the aid of a multimeter which is a universal instrument for measuring voltage, current, and resistance. Multimeters may possess a low internal resistance, and can therefore cause a noticeable reaction in the circuit being measured, when they are used as voltmeters. In order to be able to compare the measurements made with a multimeter to the data given in check voltage and resistance charts, it is necessary to use a multimeter of the same type as was used in compiling the charts.

If an instrument of another type is used, it is necessary to ascertain whether the internal resistance of the given instrument is approximately the same as that of the instrument used in compiling the charts. But even if these requirements are met, the measurement results may differ by 10-20 per cent, as compared to the charts, due to spread in the parameters of the components of a normally functioning circuit.

Consequently, a fault can be said to exist if the measurement results differ by more than this amount in comparison to the data given in the charts. In some cases the permissible departure is indicated in the instructions for aligning the equipment.

Review Questions

1. What is special about checking the correctness of connections in the case of rigid and standardized hookups?

2. What is the purpose of check voltage and resistance charts, and how to use them?

3. What kind of faults are known and what are the procedures for finding them?

4. What is the procedure for finding faults in supply systems?

5. What is the procedure for finding faults in consecutive functional circuits?

6. What is the procedure for finding faults in functional circuits in which the signals are separated and in systems with a common output and several inputs?

7. What is the procedure for finding faults inside a stage?

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CHAPTER V

Adjusting and Testing Supply Sources

5.1. PARAMETERS AND CHARACTERISTICS OF SUPPLY SOURCES

For the operation of radioelectronic circuits various d.c. and a.c. voltages are required. The primary source of electric power in most cases is an a.c. mains: commercial mains with a frequency of 50 hertzes and voltages of 110, 127, or 220 volts, as well as local a.c. networks of aircraft and rockets, with frequencies of several hundreds of hertzes.

Alternating voltages of various amplitudes can be obtained with the aid of transformers. A power transformer usually has several secondary windings, some of which step the primary voltage up and some, down.

Direct voltages are obtained with the aid of rectifiers which convert a.c. voltage into d.c. Rectifiers include transformers, to the secondary windings of which are connected rectifier valves or semiconductor diodes which possess a low resistance to current in one direction and a very high resistance to current in the opposite direction. As a result, current of one direction (rectified current) flows through the load that is connected in series with the rectifier.

Figure *44a* shows the circuit of a half-wave rectifier. During the positive half-cycle of voltage V_2 in the secondary winding of transformer *Tr*, the diode resistance is low, and the full voltage of the secondary winding is applied tc load resistance R_l. The shape of the current i_2 in the loac repeats that of the positive voltage half-cycle. The instan taneous value of the current

$$i_2 = \frac{v_2}{R_l + R_i}$$

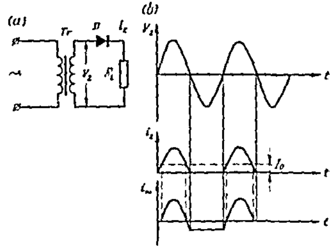


Fig. 44. Half-wave rectifier
(a) circuit; (b) voltage and current curves

where v_2=instantaneous value of the voltage across the secondary winding of the transformer
R_f=forward resistance of the diode

During the negative half-cycle of voltage v_2 no current flows through the load ($i_2=0$), because the diode has a very high reverse resistance. Current i_2 can be decomposed into d.c. component I_0 and a.c. component $i\infty$ (Fig. 44b).

In a half-wave rectifier circuit, the a.c. component of the rectified current has the same frequency as that of the a.c. mains, i.e., the ripple frequency of the rectified current is equal to the mains frequency. To supply the anode, screen-grid, and grid circuits of valve equipment and the collector and emitter circuits of transistor equipment, the ripple must be reduced to a very low amplitude.

To smoothen the ripple use is made of filters, typical circuits of which are shown in Fig. 45.

Any type of filter can be regarded as a voltage divider with different ratios of division for the d.c. and a.c. components. Choke L (Fig. 45a) and resistor R_f possess a much lower resistance to direct current in comparison with the

load resistance R_l. Therefore, they little affect the value of the rectified voltage.

In respect of the a.c. component of the rectified current, the load is shunted by the low resistance of filter capacitor C_f. The resistance to alternating current of filter choke L and of filter resistor R_f is much higher than that of the filter capacitor. Therefore, the a.c. component of

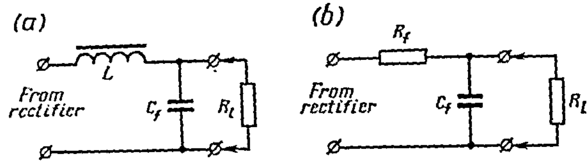


Fig. 45. Filter circuits

(a) LC type; (b) RC type

the rectified voltage nearly fully drops across them, while a very small portion of the a.c. component of the rectified voltage drops across filter capacitor C_f and the load that is connected in parallel to it.

The filter may consist of one or several inverted-L meshes. In addition, a capacitor is often connected across the input of an RC- or LC-filter. This capacitor and the internal resistance of the rectifier also form an inverted-L mesh of the RC type. From this it follows that the efficiency of employing a capacitor at the filter input depends on the internal resistance of the rectifier. The higher this resistance the greater the smoothing effect of the capacitor.

The higher the ripple frequency, the lower the reactance of the filter capacitor and the higher the reactance of the filter choke. Therefore, in the case of both LC and RC filters, the ripple voltage across the load decreases with an increase in the ripple frequency. In a full-wave rectifier (Fig. 46*a*) the ripple frequency is double that of the mains frequency (Fig. 46*b*), and this means that for smoothening the ripple it is possible to use a cheaper filter (employ a filter capacitor of lower capacitance or a filter choke of lower inductance). Rectifiers supplied by three-phase a.c. mains have a ripple frequency which is three or six times

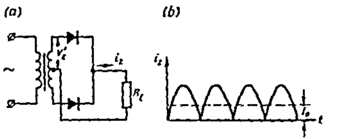


Fig. 46. Full-wave rectifier
(a) circuit; (b) current curve

higher than the mains frequency, depending on the rectifier circuit.

The relative magnitude of the ripple voltage at the output of the rectifier filter is conventionally determined by the *ripple factor*

$$K_r = \frac{V_a}{V_0}$$

where V_a=amplitude of the ripple voltage at the filter output

V_0=d.c. component of the rectified voltage

The following are among the basic parameters of rectifiers:

$V_{0\,rat}$=rated rectified voltage, i.e., the voltage which is obtained across the rectifier output at the rated load

$I_{0\,rat}$ =rated rectified current

K_r =ripple factor

P_{cons} =power consumption (the power which the rectifier consumes from a.c. mains)

From electrical engineering we know that $P_{cons}=VI_{\cos\varphi}$, where V and I are the effective values of the current and voltage of the transformer primary winding, and φ is the phase angle between them. The useful power which the rectifier supplies to the load is

$$P_0 = V_0 I_0$$

This power can be considerably lower than the consumed power, since part of the consumed power is lost in heating

the windings and core of the transformer, the rectifier anode, and in the rectifier filter.

When the load is disconnected, i.e., under no-load conditions, power is lost mainly in the transformer core, what is more it is nearly of the same value as that lost in the core with a rated load connected to the rectifier. On the other hand, the losses in the transformer windings, the rectifiers, and filters increase with an increase in the load current. An increase in the load current likewise causes a reduction in the voltage at the rectifier output due to the increased voltage drop across its internal resistance, including the resistance of the transformer secondary winding, the rectifier valve, and the filter choke or resistor.

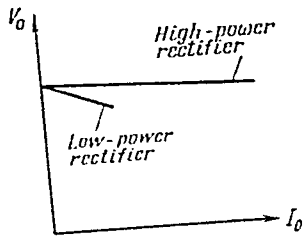


Fig. 47. Load characteristics of non-stabilized rectifier

The voltage at the output of a non-stabilized rectifier depends on the load current according to the load characteristic of the rectifier, the shape of which is shown in Fig. 47. Low-power rectifiers employ thinner wire for transformer secondary windings and choke windings, and also rectifier valves with a high internal resistance. Therefore, in the case of such rectifiers, the output voltage decreases more with an increase in the load current than in the case of high-power rectifiers.

Another factor that causes the rectifier output voltage to vary is a fluctuation in the supply mains voltage. Usually, this voltage fluctuates within ±10 per cent, and sometimes within ±20 per cent. Sharp variation in the mains voltage occurs, for example, when high-power equipmen of the shop-consumer is switched off for a dinner break. All power consumers connected with the given shop by common three-phase supply mains or a common transfomer will "feel" the variation in mains voltage to a great or lesser degree. The voltage at the output of a non-stabized rectifier will change in proportion to the change in the mains voltage. For example, if the mains voltage chang

by 10 per cent, the voltage at the rectifier output will change by the same percentage. Significant changes in the rectified voltage due to variations in the mains voltage or the load current are in many cases impermissible, and in order to avoid them, voltage stabilizers are connected to the rectifier output.

Any voltage stabilizer includes a nonlinear resistance connected in series with the load (Fig. 48). If the mains voltage increases, the nonlinear resistance increases, and voltage drop V_2 across it increases by such an amount that voltage V_0 remains practically constant. With an increase in the load current there is a decrease in voltage V_1 due to the increased voltage drop across the internal resistance of the rectifier, but simultaneously the nonlinear resistance decreases, and voltage V_2 decreases so that V_0 remains practically the same.

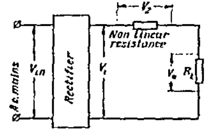


Fig. 48. Diagram explaining operating principle of stabilizer

The stabilizing properties of a rectifier are characterized by the current and voltage *stabilization factor*.

The voltage stabilization factor

$$K_v = \frac{\Delta V_{in}}{V_{in}} : \frac{\Delta V_0}{V_0}$$

It shows how many times the relative change in mains voltage ΔV_{in} exceeds the relative change in output voltage ΔV_0. For example, if the mains voltage changes by 10 per cent and the output voltage by 0.1 per cent then

$$K_v = \frac{10}{0.1} = 100$$

The current stabilization factor

$$K_i = \frac{\Delta I_0}{I_0} : \frac{\Delta V_0}{V_0}$$

It shows how many times the relative change in load

urrent ΔI_0 exceeds the relative change in output voltage ΔV_0 of the stabilized rectifier.

Thus, if the load current changes by 50 per cent and voltage V_0 by 2 per cent, then the current stabilization factor

$$K_i = \frac{50}{2} = 25$$

Stabilizers do not only reduce the effect of the mains voltage and the load current on the output voltage, but also smoothen the ripple.

5.2. CHECKING PARAMETERS AND ADJUSTING RECTIFIERS

Checking non-stabilized rectifiers. Non-stabilized rectifiers require no adjustment. If the wiring has been made correctly and all the components (transformers, valves, filter) are in order, the rectifier should conform to the specifications, therefore the task of the adjuster is to check the rectifier for working ability and its parameters for conformity to the requirements of the specifications. Departure from the requirements of the specifications indicates a mistake in assembly and wiring or departure from the rated value on the part of one or another component of the rectifier.

In the case of a non-stabilized rectifier, its parameters are checked and its load characteristics measured with the aid of the circuit shown in Fig. 49. The autotransformer serves for setting the rated voltage at the input of the rectifier and for testing it at decreased and increased mains voltages.

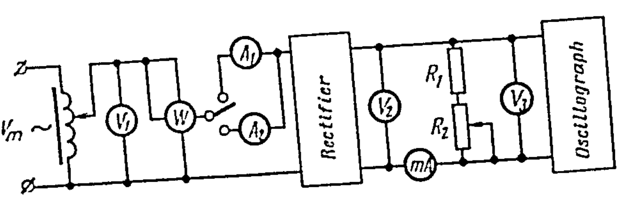


Fig. 49. Hookup for testing non-stabilized rectifier

he required voltage at the rectifier input is set according a.c. voltmeter V_1. Wattmeter W measures the power sumed from the mains. A.c. ammeters A_1 and A_2 serve measuring the current consumed under no-load and load nditions. It is possible to use one multi-range ammeter, t in this case it is necessary first to set a sufficiently high easuring range, so as to avoid damaging the meter in case a short-circuit in the transformer or the rectifier circuit.

The d.c. voltage at the output of the rectifier is measured ith d.c. voltmeter V_2, the internal resistance of which hould be such that it does not consume more than one per cent of the rated rectifier current. For this purpose use can be made of moving-coil voltmeters with a sensitive indicator or d.c. valve voltmeters.

Moving-coil milliammeter mA serves for measuring the d.c. component of the rectifier load current. Its resistance should be low compared to the rated load resistance determined by the equation:

$$R_{rat} = \frac{V_{0rat}}{I_{0rat}}$$

The a.c. component of the rectified voltage (ripple voltage) is measured with the aid of an oscillograph or a.c. peak valve voltmeter V_3 with a blocked input. Voltmeter scales are calibrated in effective values of a.c. voltage, and therefore their readings should be multiplied by $\sqrt{2}$ to determine the peak value of the ripple.

Most modern oscillographs are provided with two voltage scales: one is calibrated in effective and the other, in amplitude voltage values. When measuring the ripple amplitude, one should take the reading of the amplitude-valu scale.

An important advantage of the oscillograph, as compare to the voltmeter, is the possibility of observing the sha of the ripple voltage. Knowing the shape of the ripple vol age of a sound rectifier, it is possible to discover certa faults. Thus, asymmetry of the two halves of the second windings of power transformer in a full-wave rectif changes the shape of neighbouring half-cycles of the rip voltage, while faults of the filter bring about sharp cha ... and amplitude of this voltage, etc.

Rectifier parameters are determined by the readings of instruments included in the testing circuit:

power consumption, by the reading of the wattmeter;

useful rectifier power $P_0=V_0I_0$, by the readings of instruments V_2 and mA;

ripple factor, by the readings of d.c. and a.c. voltmeters V_2 and V_3, according to the formula

$$K_r=\frac{V_a}{V_0}$$

where V_0=d.c. component of the rectified voltage, measured by instrument V_2

V_a=amplitude of the ripple voltage measured by instrument V_3

To measure the load characteristic of the rectifier, it is necessary to vary the load current with the aid of variable resistor R_2 and take down the corresponding values of rectified voltage. An example of a load characteristic is shown in Fig. 47.

Adjusting and checking stabilized rectifiers. When testing stabilized rectifiers, it is necessary to make all the measurements described above and, in addition, to determine the voltage and current stabilization factors. Considerable difficulties develop when measuring the stabilization factor of electronic stabilizers. These stabilizers have very high stabilizing properties. Their stabilization factor can attain several hundreds. This means that the output voltage of the rectifier changes very little. For example, if the mains voltage changes by 10 per cent, then with a stabilization factor of 100 the voltage at the output of the stabilizer will change by 0.1 per cent.

A small change in output voltage ΔV_0 can be measured with the aid of the compensation method (Fig. 50). By means of the autotransformer the rated mains voltage is set according to voltmeter V_1 and the output voltage of the stabilized rectifier is measured with voltmeter V_2. With the aid of potentiometer R_2, the pointer of voltmeter V_3, which has zero reading in the middle of the scale is set to the zero position. Next, the supply mains voltage or the value of load resistor R_l is varied within given limits and the variation in

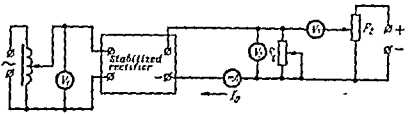


Fig. 50. Hookup for testing stabilized rectifier

output voltage ΔV_0 is read from voltmeter V_2. Variation in the load current is determined from the equation

$$\Delta I_0 = I'_0 - I''_0$$

where I'_0=reading of the milliammeter under the rated operating conditions of the rectifier

I''_0=reading of the milliammeter with a variation in the supply mains voltage or the value of the load resistor

One of the simplest circuits of a voltage stabilizer employing a voltage stabilizing tube is shown in Fig. 51*a*, and its volt-ampere characteristic, in Fig. 51*b*. The voltage stabilizing tube is characterized by rated voltage and by the range of current variation from I_1 to I_2 within which the voltage across the stabilizing tube remains practically constant. If the mains voltage or the load resistance varies, the current flowing through resistor R_1 varies as well as the voltage drop across this resistor, while voltage across the stabilizing tube and across the load that is connected in

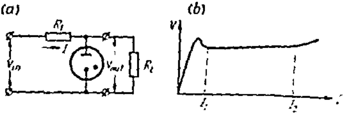


Fig. 51. Voltage stabilizer employing stabilizing tube
(a) circuit; (b) volt-ampere characteristic

parallel to it remains practically constant if the curre[nt] through the stabilizing tube remains within the range I... to I_2.

The stabilization factor of a stabilizer employing a stabi-lizing tube is the greater the higher the resistance of R_1. However, an increase in the resistance of R_1 demands an increase in input voltage V_{in}. Actually, the voltage dropp-ing across resistor R_1 is $V_1=IR_1$, while the input voltage of the circuit is $V_{in}=V_1+V_{out}$. With the given current I the voltage which is to be applied to the stabilizer circuit increases with an increase in the resistance of R_1.

This requires the use of a more expensive rectifier de-signed for a higher power and a higher output voltage. On the other hand, increasing the resistance of R_1 does not bring about a proportional increase in the stabilization factor. In practice this resistance is selected such that about $^1/_3V_{in}$ drops across it. The stabilization factor of such a circuit does not exceed 10.

Much higher stabilizing properties are provided by elec-tronic stabilizers, a common circuit of which is shown in Fig. 52.

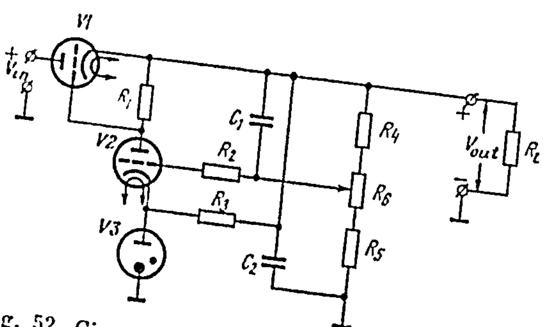


Fig. 52. Circuit of electronic voltage stabilizer

With an increase in the mains voltage there are a pro-portional increase in the voltage at the stabilizer input and, at the first instant, a considerable increase in the voltage at its output. A similar increase in the output volt-age will also take place in case of a rapid decrease in the

load, i.e., an increase in the value of load resistor R_l. This causes an increase in the voltage drop across resistors R_4, R_5, R_6, and, consequently, an increase in the potential of the control grid of valve *V2*. The cathode potential of this valve remains practically constant, since it is stabilized by the circuit including resistor R_3 and voltage stabilizing tube *V3*.

Thus, the potential of the grid with respect to the cathode of the valve increases nearly as much as does the potential of the grid with respect to the chassis. This causes an increase in the anode current of valve *V2* and an increase in the voltage drop across resistor R_1. Since resistor R_1 is simultaneously included in the grid circuit of regulating valve *V1*, its grid potential decreases while its internal resistance increases, thus decreasing the voltage at the output of the stabilizer.

And so, an increase in the mains voltage or in the load resistance brings about an increase in the internal resistance of regulating valve *V1*. With proper selection of the operating conditions of valves *V1* and *V2* the resultant variation in the output voltage will be low.

Capacitor C_1 reduces the ripple in the rectified voltage. Practically all the ripple voltage is applied to the grid of valve *V2* via this capacitor and resistor R_2.

Adjustment of a voltage stabilizer includes:

selection of the operating conditions of valve *V2* (the grid potential of this valve with respect to the chassis should be somewhat lower than the rated stabilizing tube voltage, so that the grid has a negative voltage with respect to the cathode, and the operating point is located on the steep section of the anode-grid characteristic of the valve; final selection of the operating conditions of this valve is made with the aid of potentiometer R_6);

selection of resistors R_4 and R_5 (their resistance is selected such that it is possible to adjust the output voltage of the stabilizer within certain limits with the aid of potentiometer R_6 without violating the requirements in respect of the stability of this voltage);

selection of resistor R_1 (it is selected so that at the rated operating conditions of the regulating valve the rated output voltage is obtained; simultaneously the operating point

of valve $V1$ should be on the steep section of its chara ristic).

For stabilizing current use is often made of barrett The circuit of a current stabilizer employing a barrette shown in Fig. 53a, and the volt-ampere characteristic o barretter, in Fig. 53b.

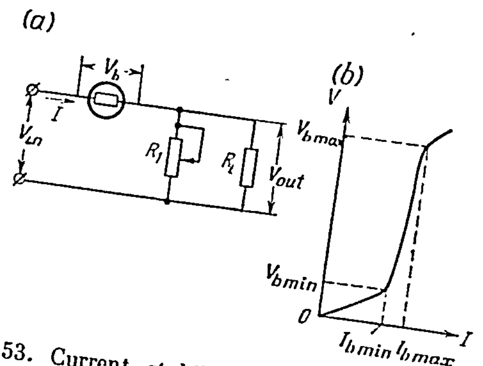


Fig. 53. Current stabilizer employing barretter
(a) circuit; (b) barretter volt-ampere characteristic

With an increase in the supply mains voltage or a decrease in the load resistance, the resistance of the barretter increases, while the current I in the circuit changes slightly, if the voltage dropping across the barretter remains within the working range

$$V_{b.\,\max} \text{ to } V_{b.\,\min}$$

Barretters are designed for definite loads. Selection of the necessary operating conditions of a barretter can be made with the aid of variable resistor R_1, if for bringing the barretter within the limits of the working range it is necessary to increase the current flowing through it.

For stabilizing the a.c. voltage supplying a rectifier, wide use is made of electromagnetic voltage stabilizers. The circuit of an electromagnetic stabilizer is shown in Fig. 54. Choke Ch_1 operates under saturation conditions, when the current and the magnetic flux are not linearly interdependent. This means that the inductance of choke Ch_1 depends

on the current flowing through it. Choke Ch_2 is not saturated, therefore its inductance does not depend on the current.

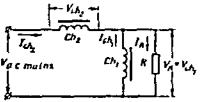


Fig. 54. Circuit of electromagnetic stabilizer

With an increase in the supply mains voltage the inductance of the saturated choke decreases and, consequently, its reactance decreases. This causes a redistribution of the voltages between the saturated and non-saturated chokes: as a result, the voltage across the non-saturated choke increases nearly as much as the input voltage does, while the voltage across the saturated choke and the load connected in parallel to it changes a little.

When operating into a high-ohmic load, it is possible to obtain good stabilization with the aid of a bridge circuit (Fig. 55). Two arms of the bridge contain identical resis-

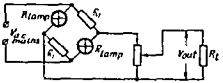


Fig. 55. Bridge stabilizer circuit

tors R_1, while two other arms include incandescent lamps, the resistance of which R_{lamp} is nonlinear: it increases with an increase in current.

Under rated operating conditions the bridge is unbalanced so that $R_{lamp} < R_1$. With an increase in the mains voltage the resistance of the lamps increases, thus decreasing the unbalance of the bridge, since balance of the bridge corresponds to the equality $R_{lamp} = R_1$.

If all the arms of the bridge included resistors, then with an increase in the mains voltage, output voltage V_{out} would increase proportionally to the increase in the input volt-

age. Since the unbalance of the bridge decreases due to the inclusion of the incandescent lamps, the resultant change in the output voltage can be made very small if the bridge is adjusted correctly. Adjustment amounts to the selection of the resistance of resistors R_1.

5.3. UNIVERSAL SUPPLY SOURCES

During laboratory investigation of individual units and during their adjustment under the conditions of experimental production, it is convenient to make use of universal supply sources for supplying voltage to the anode, grid, and heater circuits. They usually include stabilized rectifiers for supplying anode and grid circuits and a number of secondary windings in the power transformer for obtaining various non-stabilized a.c. voltages of 2; 2.5; 4; 6.3, and 12 volts for supplying heater circuits.

As an example let us consider the circuit of a universal supply source shown in Fig. 56. The circuit is supplied from a.c. mains of 220 volts, 50 hertzes. It is switched on by means of on/off switch Sw_1. Fuse F_1 provides protection against overloads. Secondary windings *1*, *2*, *3*, *4*, and *5* of transformer *Tr* serve for supplying heater circuits and are protected against overloads by fuses. The stabilized rectifier for supplying anode and screen-grid circuits employs valves *V1* and *V2* in a full-wave circuit and is protected against overloads by fuse F_2. The rectifier is loaded by two filters, one of which is included in the anode supply circuit and the other, in the screen-grid supply circuit.

The anode supply circuit filter consists of choke Ch_2, capacitors C_1, C_2, C_3 at its input and capacitors C_5, C_6 at its output. The screen-grid supply circuit filter consists of choke Ch_1 and capacitor C_4. Regulating valves *V4*, *V6*, *V10*, *V11*, and *V12* are connected in parallel and provide a rated current of 300 milliamperes. Control valve *V7* has an anode load which consists of resistors R_8, R_9, and R_{10}.

The operating conditions of this valve are set with the aid of potentiometer R_{28}. A constant cathode potential is provided for valve *V7* by voltage stabilizing tube *V9* which

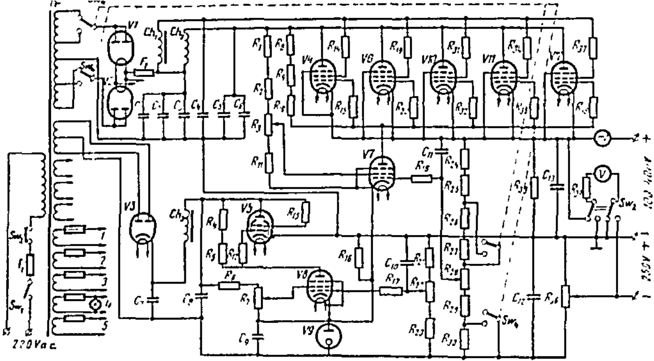


Fig. 56. Circuit diagram of stabilized rectifier

simultaneously supplies a constant voltage to the cathode of control valve $V8$ of the second stabilized rectifier.

The second rectifier, supplying 0 to 250 volts, employs a full-wave circuit and two-anode rectifier valve $V3$. The rectified voltage is passed through a filter formed by choke Ch_3 and capacitors C_7 and C_8. Regulating valve $V5$ is designed for passing a rated current of 5 milliamperes. The operating conditions of control valve $V8$ are set with the aid of potentiometer R_{22}.

To ensure the safety of the attendant personnel, interlock Sw_3 is provided; it breaks the primary supply circuit when the device is removed from its case. The output voltages are checked with the aid of moving-coil voltmeter V which can be switched by means of switch Sw_2 to the output of either rectifier. The possibility of measuring the output voltages of either rectifier is provided by two-pole switch Sw_2.

The load current of the 100-400-volt stabilized rectifier is measured by moving-coil milliammeter mA. There is no provision for measuring the load current of the 0-250 V rectifier.

Adjustment of the voltage from 100 to 400 volts in the positive-voltage rectifier is obtained by simultaneous switching of the taps in the secondary winding of the transformer and of the resistors of the output voltage divider with the aid of switch Sw_4. This provides two ranges of output voltages: one from 100 to 250 volts and the other from 250 to 400 volts. Within each of these ranges the output voltage can be varied continuously by means of potentiometer R_{28} which varies the control-grid voltage of valve $V7$.

Negative output voltage is adjusted by means of potentiometer R_{38} from 0 to 250 volts.

Faults of supply sources. Fault finding in supply sources is done according to the regular procedure. During external examination, it is necessary to clean the instrument of dust, since pollution can be the cause of a fault. Most of the common circuit faults can be detected during external examination, as well as with the aid of the indicating and protective devices incorporated in the supply unit.

Let us consider some of the more common faults.

Fault	Possible cause
1. When the unit is energized, the signal lamp does not light up, but the voltmeter gives a reading	The signal lamp has burnt out or has worked loose
2. When the unit is energized, the signal lamp does not light up, the valves do not heat up, and the voltmeter gives no reading	Blown mains fuse, faulty supply cable, no contact in the interlock or in the on/off switch
3. When the unit is energized, the signal lamp lights up, the voltmeter indicates the presence of voltage, but there is no current in the load	Faulty milliammeter, an open in the output circuit
4. When the unit is energized, the signal lamp lights up, the voltmeter indicates a negative voltage, but does not indicate the presence of a positive voltage. The valves heat up and the voltage stabilizing tube glows	Blown high-voltage fuse F_2, faulty rectifier valves *V1* and *V2* or switch Sw_4, an open in the circuitry or the power transformer
5. The unit operates, but with a small increase in the load the ripple increases, and with a heavy load, the output voltage falls	One of the rectifier valves is faulty
6. The unit operates, but there is no stabilization of the output voltage, the anodes of some of the valves are overheated, while others remain cold	Some of the regulating valves of the positive voltage stabilizer are faulty
7. The voltage of 100-400 volts cannot be adjusted and is too high	Faulty control valve *V7*
8. The positive voltage cannot be adjusted and is low	An open in the anode circuit of the control valve or in voltage divider $R_{24}-R_{20}$, no contact in the control-grid circuit of this valve, broken-down capacitor C_{11}
9. The negative voltage of 0-250 volts is missing	No contact in potentiometer R_{25} or an open in the output circuit, faulty rectifier valve *V3* or valve *V5*
10. Sparking in rectifier valve *V3*	Broken-down filter capacitor C_7 or C_8 or a short in the circuit
11. The negative voltage is considerably above the normal, and there is no stabilization	An open in the screen-grid circuit of valve *V8*, an open in output voltage divider $R_{21}-R_{23}$, faulty valve *V8*

Fault	Possible cause
12. The negative voltage is considerably below 250 volts, and there is no stabilization	An open in the anode circuit of valve $V8$, broken-down capacitor C_{10}, fault in voltage divider $R_{21}—R_{23}$
13. Voltage stabilizing tube does not glow, there is no stabilization	Faulty stabilizing tube or capacitor C_9 which shunts it
14. No voltage at one of the low-voltage a.c. outputs	One of fuses F_2 to F_7 has blown

Having located the faulty section of the circuit, it is necessary to find the faulty component by external examination, by checking voltage or resistance, by replacement, or any other method.

Review Questions

1. What are the functions of rectifiers and the basic requirements they are to meet?
2. Draw a circuit for testing non-stabilized rectifiers and explain the purpose of the measuring instruments. What types of instruments (meters) are suitable for checking various parameters and measuring load characteristics?
3. Explain the principle of operation, the functions of the components, and the procedure for adjusting an electronic stabilizer.
4. How can the stabilization factor be measured?
5. What are the possible faults of a universal supply source, referring to the circuit diagram in Fig. 56?

CHAPTER VI

Adjusting and Testing Amplifiers

6.1. PARAMETERS AND CHARACTERISTICS

By *amplifiers* are meant electronic circuits designed for amplifying the voltage or power of signals without changing their shape.

Audio frequency amplifiers are those which amplify audio oscillations within the range of 20 hertzes to 20 kilohertzes.

The band of frequencies amplified by audio amplifiers may be narrower than the range of audio frequencies. Thus, fo[r] amplifying speech a narrower band is required than fo[r] amplifying music.

Amplifiers of current and voltage pulses possess variou[s] bandwidths, depending on the duration and shape of th[e] pulses to be amplified. Pulse amplifiers employed in rada[r] and television possess a broad passband. Thus, amplifie[rs] for amplifying image signals (video amplifiers) possess [a] passband from several tens of hertzes to several meg[a]hertzes.

Radio frequency amplifiers are designed for amplifying rad[io] frequency signals covering a certain spectrum of frequencies. They possess a relative low frequency ratio $\frac{f_{max}}{f_{min}}$, whe[re] f_{max} and f_{min} are the maximum and minimum frequenci[es] of the band of oscillations being amplified.

The *sensitivity* of an amplifier is its ability to ampl[ify] weak signals. By the sensitivity of an amplifier is mea[nt] the minimum input voltage which at the amplifier o[utput] produces a power sufficient for the operation of a ... ing circuit or an actuating device (loudspeaker, ...

By *voltage amplification factor* is meant the ratio of output voltage of the amplifier to its input voltage

$$K = \frac{V_{out}}{V_{in}}$$

The dependence of the amplification factor (or gain) o the signal frequency is known as the *frequency characterist* (or *response*). The frequency response of an amplifier i shown in Fig. 57*a*. Within that band of frequencies wher the amplification facto remains constant, all components of the signal are amplified to the same degree. Where the frequency response "dips", signals having components outside the "flat" section of the response will be distorted. For example, if the response sags at low frequencies, the low-frequency components of the signal will not be reproduced so well.

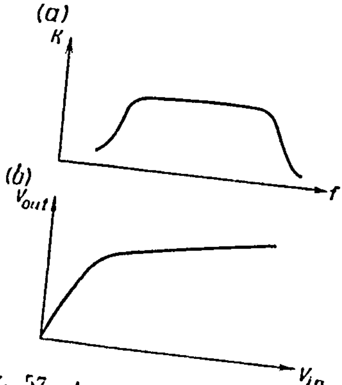


Fig. 57. Amplifier characteristics
(*a*) frequency; (*b*) amplitude

The ratio of the gain on a given frequency to the gain on a middle frequency is known as the *frequency distortion factor*. The band of frequencies within which the frequency distortion factor does not exceed a given value is known as the *passband* or *bandwidth* of the amplifier.

On the basis of the frequency response of an amplifier, it is possible to determine not only which band of frequencies the amplifier will pass without noticeable frequency distortion but also what selective properties it possesses. By *selectivity* is meant the ability of an amplifier to single out the useful signal that occupies a definite frequency band from the group of signals applied to its input, the latter having frequencies close to the extreme frequencies of the amplifier passband.

The dependence of the output voltage of an amplifier on its input voltage is known as the *amplitude characteristic*

or *response*. The amplitude response of an amplifier is shown in Fig. 57*b*. If the amplitude characteristic is not a straight line, this indicates that nonlinear distortion occurs in the amplifier.

When the signal passes through reactive parts of the amplifier circuit the various components of the signal are subjected to different phase shifts. The dependence of the phase angle between the input and output voltages of an amplifier on the frequency of the voltage being amplified is known as the *phase response* of the amplifier. Phase distortion of the signal develops if the phase response is nonlinear.

The ability to amplify weak signals without any interference is limited in practice by the internal noise of an amplifier. This noise voltage is developed by electronic valves, transistors, resistors, and certain other components of the amplifier circuit. The ripple in the voltage supplying the amplifier develops corresponding oscillations of the output voltage which are known as the *a.c. hum*. The level of internal noise is one of the most important characteristics of amplifiers designed for amplifying weak signals. For power amplifiers the most important parameters are the power output and the efficiency.

A hookup for testing amplifiers is shown in Fig. 58. A generator must be calibrated both in the frequency and

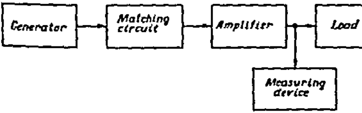


Fig. 58. Hookup for testing amplifier

in the amplitude of the output voltage or the output power. The measuring device connected in parallel to the load must have an input resistance many times higher than

that of the load. Among the measuring devices used are valve voltmeters, oscillographs, nonlinear-distortion meters.

Measuring Frequency Characteristics

There are two basic methods of measuring frequency characteristics:

the method of supplying the amplifier by turns with voltages of different frequencies but of the same amplitude. The frequency of the voltage applied can be varied manually or automatically, with the output voltage being measured by a voltmeter in the first case and being observed on the screen of an oscillograph in the second case;

the method of supplying the amplifier with a signal that contains a whole spectrum of many different frequencies (for example, a square-wave signal). The parameters of the amplifier can be judged by comparing the amplitude and shape of the signal at the input and the output of the amplifier. A square pulse is applied to the input from a pulse generator, and the output pulse is observed and its amplitude measured with the aid of a pulse oscillograph.

To measure point-by-point frequency characteristics, it is possible to use the hookup shown in Fig. 58. Instead of an actual load, a dummy load can be connected, i.e., a resistor equal in value to the load resistance.

When measuring frequency characteristics, the gain can be measured in two ways:

the amplifier input voltage V_{in} is kept constant. The generator frequency is varied and the voltage at the output of the amplifier measured. This voltage will depend on the frequency in the same way as the amplification factor $K=V_{out}/V_{in}$ does, because V_{out} is measured at a constant V_{in};

the amplifier output voltage is maintained constant on various generator frequencies. In this case the shape of he gain curve K will be the reverse to that of the frequen-y response curve. The maximum gain will correspond to $_{in \cdot min}$ and vice versa.

An advantage of the second method is that it makes it asier to avoid nonlinear distortion, because the amplitude

of the output voltage is maintained constant throughout and of such a magnitude when there is no nonlinear distortion. To avoid nonlinear distortion when using the first method of measuring the frequency response, it is necessary to maintain such a V_{in} at which a normal voltage on the frequency corresponding to the maximum gain is produced at the amplifier output.

A disadvantage of the methods of measuring the frequency response point by point, which have been considered, is the amount of work that they require, but an advantage is their high precision. That is why point-by-point measurement of frequency response is restricted to laboratories.

Under the conditions of batch and serial production, the measurement of frequency response is automatized. A block diagram for measuring with the aid of a frequency response meter, which allows the process of measuring the frequency response to be automatized, is shown in Fig. 59*a*. The output of a wobbulator is fed to the input of the amplifier, and the input of the oscillograph (frequency response meter) is connected to the output of the amplifier.

The amplitude of the output voltage of the wobbulator does not vary with variation of its frequency, and therefore the voltage at the output of the amplifier has the shape of its frequency response: the amplitude of the voltage varies in step with variations in the gain (Fig. 59*b*).

In order to obtain the customary frequency response curve, the output voltage of the amplifier is rectified and a filter singles out the envelope which is shaped like an ordinary frequency response curve (Fig. 59*c*). The frequency sweep of the wobbulator is synchronized with the sweep of the oscillograph, so that a stationary frequency response curve is obtained on the oscillograph screen.

The frequency calibrator serves to superimpose frequency markers on the frequency response curve. The output voltage of the calibrator, which is made up of a series of harmonics of a crystal oscillator, is supplied to a mixer. The mixer is also supplied with the voltage of the wobbulator. At the output of the mixer filter there develop voltage pulses in those brief intervals of time when the frequency of the wobbulator is close to that of one of the harmonics of the calibrator. For example, if the fundamental frequency of

the calibrator is 1 megahertz, its harmonics will have fr-
quencies of 1, 2, 3 megahertzes, etc.

If the generator wobbles over a frequency range of 20-3
megahertzes, then voltage pulses will develop at the filte
output at the generator frequencies of 20, 21, 22, 23, 24,

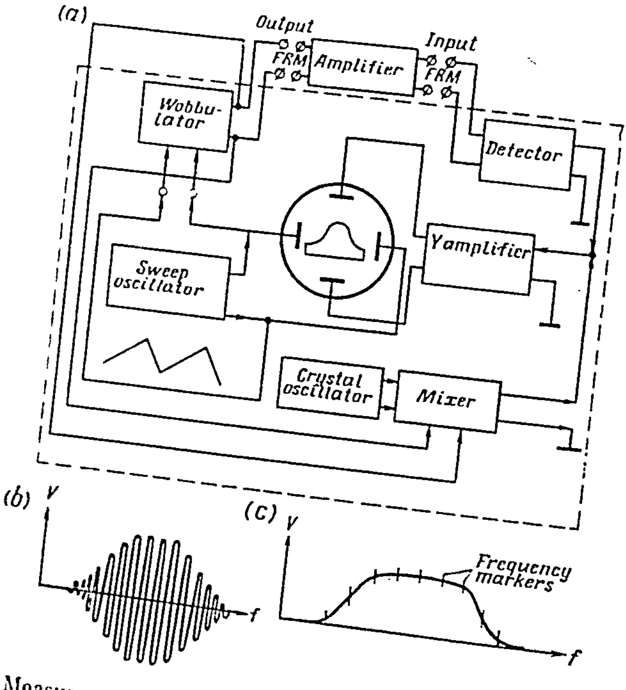


Fig. 59. Measurement of frequency response with the aid of frequency response meter

(a) block diagram; (b) voltage at amplifier output (before detector); (c) amplifier frequency response curve with frequency markers

25, 26, 27, 28, 29, 30 megahertzes. These voltage pulses
are applied to the oscillograph input (along with the output
voltage of the amplifier) and produce markers on the fre-
quency response curve spaced 1 megahertz apart. These fre-
quency markers can be used, for example, for determining
the passband of the amplifier.

This method of observing frequency response curves is exceptionally important when adjusting radio circuits possessing a complex frequency characteristic. By manipulating the controls that adjust the frequency response and simultaneously observing the effect of these controls on the oscillograph screen, the adjuster can very quickly obtain the required frequency response.

Pulse method of evaluating the frequency and phase distortion. Measuring the frequency response of broad-band amplifiers discussed above is rendered difficult because of the necessity of sweeping the frequency of the frequency modulated generator over a broad band, while maintaining a constant amplitude. In addition, very important in the operation of broad-band amplifiers is phase distortion, and measuring the phase characteristics of an amplifier is a very labourious job. That is why when testing broad-band amplifiers use is often made of the pulse method of evaluating frequency and phase distortion. A hookup for measurements by the pulse method is shown in Fig. 60.

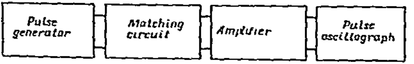


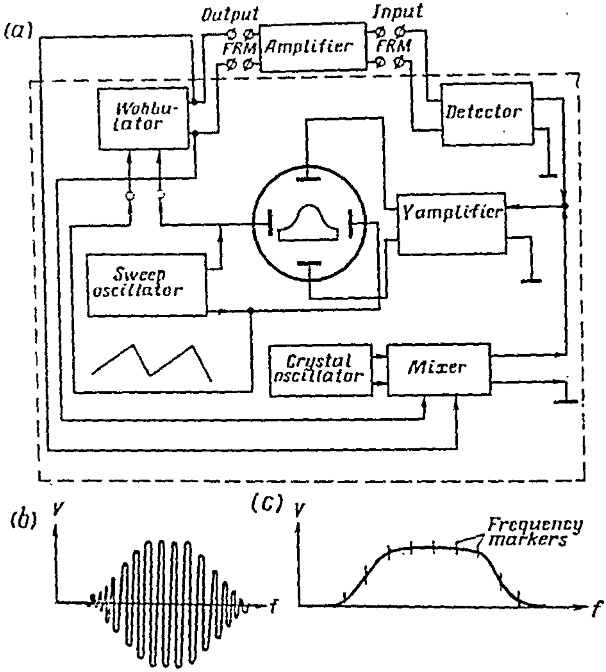
Fig. 60. Hookup for measurements by pulse method

The input of a broad-band amplifier is supplied with a square pulse from a pulse generator. The output of the generator must be so matched to the input of the amplifier with the aid of a matching circuit that there will be no distortion of the shape of the square pulse. The matching circuit connected between the generator and the amplifier is adjusted experimentally. For this the pulse at the output of the matching circuit is observed on a pulse oscillograph and, if it is distorted, the necessary adjustments are made so that there will be a square pulse directly at the input of the amplifier to be tested.

Next the oscillograph is connected to the amplifier output and the shape of the pulse is examined. By the nature

the calibrator is 1 megahertz, its harmonics will have frequencies of 1, 2, 3 megahertzes, etc.

If the generator wobbles over a frequency range of 20-30 megahertzes, then voltage pulses will develop at the filter output at the generator frequencies of 20, 21, 22, 23, 24,



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(a) block diagram; (b) voltage at amplifier output (before detector); (c) amplifier frequency response curve with frequency markers

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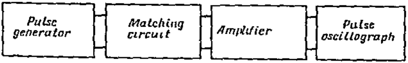

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Next the oscillograph is connected to the amplifier output and the shape of the pulse is examined. By the nature

of the deviations from a square shape one can judge of the distortion introduced by the amplifier.

6.2. AUDIO FREQUENCY AMPLIFIERS

The audio frequency amplifiers which are used for amplifying speech and music must possess sufficiently low frequency and nonlinear distortion. Nonuniformity of the frequency response leads to a wrong reproduction of the ratios between the various pitches in the sound amplified, to the stressing or attenuation of high or low notes. In the presence of nonlinear distortion, sounds appear which were absent in the signal being amplified. Phase distortion is not detected by the human ear.

Audio frequency amplifiers are also widely used in systems for converting nonelectrical magnitudes into electrical magnitudes. The transducer proper develops at its output a weak signal which must be amplified before it can be applied to a measuring or other actuating device. AF amplifiers may amplify either voltage or power, or serve as narrow-band filters for singling out a given signal from a series of others, etc.

Adjustment of AF amplifiers. The adjustment of AF amplifiers amounts to the selection of the operating conditions of valves, transistors, and other nonlinear elements and to the adjustment of correction circuits with the aid of which the necessary frequency response curve is obtained. Figure 61*a* shows the circuit of an AF amplifier ... pro- vision for correcting the frequency response on b... ...c and lower frequencies.

Let us suppose that the amplifier circuit la... tion elements. The amplifier must possess a cert... a given passband. If the resistance of anode lo... creased, the gain will increase but the p... come narrower.

With an increase in frequency, its resistance (or to be more [e]xact, reactance) decreases, shunting to an ever greater deg[re]e resistor R_a, as a result of which the gain falls. This [c]auses a dip in the frequency response on the higher frequen[ci]es (the dotted line in Fig. 61*b*).

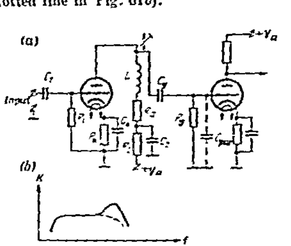

Fig. 61. Audio frequency amplifier
(a) circuit; (b) frequency response

RF choke L and capacitance C_{par} form a tuned circuit, [t]he natural frequency of which lies in the range of the higher [f]requencies of the amplifier passband or slightly higher. The [r]esultant increase in the equivalent resistance of the anode [c]ircuit with an increase in frequency boosts the frequency [r]esponse (solid line in Fig. 61*b*).

If there is a great reserve in gain, the simplest way of [b]roadening the passband in the region of higher frequencies [i]s decreasing the resistance of R_a.

The dip of the frequency response at lower frequencies [i]s due to the fact that with a decrease in frequency there [a]re an increase in the reactance of capacitor C_g, an increase [i]n the voltage drop across capacitor C_g, and a corresponding [d]ecrease in the voltage across resistor R_g, i.e., a decrease [i]n the gain.

Network R_2C_2 can be used both as a filter for decoupling [t]he given stage from the others via the anode supply source

of the deviations from a square shape one can judge of the distortion introduced by the amplifier.

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Audio frequency amplifiers are also widely used in systems for converting nonelectrical magnitudes into electrical magnitudes. The transducer proper develops at its output a weak signal which must be amplified before it can be applied to a measuring or other actuating device. AF amplifiers may amplify either voltage or power, or serve as narrow-band filters for singling out a given signal from a series of others, etc.

Adjustment of AF amplifiers. The adjustment of AF amplifiers amounts to the selection of the operating conditions of valves, transistors, and other nonlinear elements and to the adjustment of correction circuits with the aid of which the necessary frequency response curve is obtained. Figure 61*a* shows the circuit of an AF amplifier with provision for correcting the frequency response on both higher and lower frequencies.

Let us suppose that the amplifier circuit lacks correction elements. The amplifier must possess a certain gain at a given passband. If the resistance of anode load R_a is increased, the gain will increase but the passband will become narrower.

Actually, from the point of view of the AF current, connected in parallel to resistor R_a are resistor R_g and capacitance C_{par} which is equal to the sum of the parallel connected input capacitance of the following stage, the output capacitance of the given stage, and the circuitry capacitances. On the lower frequencies capacitances possess high resistance and do not affect the amplification (gai

With an increase in frequency, its resistance (or to be more exact, reactance) decreases, shunting to an ever greater degree resistor R_a, as a result of which the gain falls. This causes a dip in the frequency response on the higher frequencies (the dotted line in Fig. 61*b*).

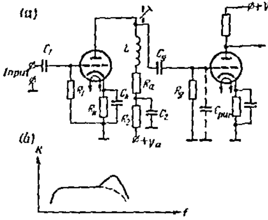


Fig. 61. Audio frequency amplifier
(*a*) circuit; (*b*) frequency response

RF choke L and capacitance C_{par} form a tuned circuit, the natural frequency of which lies in the range of the higher frequencies of the amplifier passband or slightly higher. The resultant increase in the equivalent resistance of the anode circuit with an increase in frequency boosts the frequency response (solid line in Fig. 61*b*).

If there is a great reserve in gain, the simplest way of broadening the passband in the region of higher frequencies is decreasing the resistance of R_a.

The dip of the frequency response at lower frequencies is due to the fact that with a decrease in frequency there are an increase in the reactance of capacitor C_g, an increase in the voltage drop across capacitor C_g, and a corresponding decrease in the voltage across resistor R_g, i.e., a decrease in the gain.

Network R_2C_2 can be used both as a filter for decoupling the given stage from the others via the anode supply source

for frequency correction in the region of lower frequencies. On these frequencies the anode load of the stage is the sum of resistors R_a+R_2. On higher frequencies the resistance of resistor R_2 is shunted by capacitor C_2, which brings about a reduction in the gain on medium and higher frequencies.

AF amplifiers employing transistors usually do not include frequency correction networks, since they possess a sufficiently broad passband. They employ transistors in a common-emitter circuit, which provide a relatively high gain. The output resistance of common-emitter stages is higher than their input resistance, so that maximum power gain is obtained by matching the output resistance of the previous stage to the input resistance of the following stage.

In the circuit of the capacitive-coupled amplifier shown in Fig. 62*a* matching of the stage resistances is not obtained, the input resistance of the following stage shunts the resistance of the collector circuit of the preceding stage, which reduces both the voltage and power gain.

In the circuit shown in Fig. 62*b* matching of the stage resistances is obtained with the aid of interstage transformers. These are step-down transformers, i.e., the number of turns of the primary winding included in the collector circuit is greater than the number of turns of the secondary winding included in the base circuit of the following stage.

With correct selection of the transformation ratio, a sufficiently high resistance is reflected into the collector circuit, and the gain of the stage increases. Too high a resistance cannot be reflected into the collector circuit, for this brings about saturation: the voltage between the collector and emitter approaches zero and the shape of the signal being amplified is sharply distorted.

The setting in of saturation conditions can be detected with the aid of an oscillograph, the input of whose vertical amplifier is connected to the base of the following stage.

The use of transformer coupling increases the size, weight, and cost of the amplifier. A cheaper way of matching interstage resistances is shown in Fig. 62*c*.

In between two common-emitter amplifier stages there is a common-collector stage. The stage has a high input resistance and therefore it does not shunt the output resistance

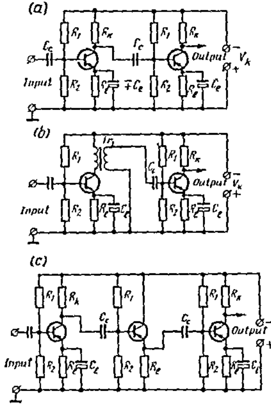


Fig. 62. Circuits of audio frequency amplifiers employing transistors
(a) capacitive-coupled; (b) transformer-coupled; (c) with emitter follower

of the first stage. It also has a low output resistance and amplifies power, making it possible to raise the power gain even in those cases when no full matching of the stage resistances can be achieved.

Shifting of the operating point along the characteristic of a transistor can be obtained by selecting the resistors connected between the base and the collector-circuit supply source. While making adjustments, it is useful to connect an oscillograph for checking the shape of the signals and for excluding distortion due both to transition into the region of saturation and to the cutoff of the collector current.

When connecting measuring instruments to transistor circuits, two things should be borne in mind.

Firstly, one should remember that the input and output resistances of transistor amplifiers are lower than those of valve amplifiers and, therefore, for both a.c. and d.c. measurements it is possible to use parallel-connected voltmeters, oscillographs, and other instruments with lower input resistance.

Secondly, unlike in valve amplifiers, the internal resistance of the source of the signals being amplified significantly affects the gain and the passband of the amplifier. Usually the input resistance of audio frequency amplifiers is very high, and it does not shunt the output of the signal source, and the voltage at the output of the generator remains the same in both no-load conditions and when it is loaded by the amplifier.

But the situation is quite different when a signal source is connected to the input of a transistor amplifier (Fig. 63).

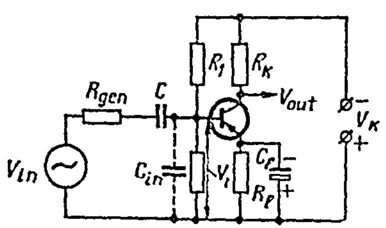


Fig. 63. Connection of signal source to input of transistor amplifier

For a given value of the e.m.f. of signal source V_{in}, voltage V_1 at the stage input depends on the internal resistance of source R_{gen} and the input resistance of the transistor. Obviously the lower it is, the higher the resistance of R_{gen} with respect to the input resistance of the transistor. What is more, if within the given band the latter depends on frequency, then voltage V_1 will also change with variation in frequency and a constant value of V_{in}. This will bring about an apparent narrowing of the passband of the amplifier. Therefore, it is important that the internal resistance of the signal source used in the adjustment and checking of the amplifier parameters should be equal to the internal resistance of the source used in operating conditions.

Let us examine the characteristic properties of checking

the parameters and measuring the characteristics of AF amplifiers.

Measuring the hum level. When testing audio frequency amplifiers it is very important to measure the a.c. hum level, since the components of hum lie within the range of audio frequencies and produce a characteristic hum or buzzing that reduces the quality of the speech or music reproduced.

To single out the a.c. hum from all the other noises, use is made of harmonic analyzers or filters tuned to the hum frequency. Figure 64 shows an example of the measurement of hum components for the case when an amplifier is supplied by a full-wave rectifier.

In this case the main hum components are mains frequency f_m and the second harmonic of this frequency $2f_m$. The hum component of frequency f_m results from pickup from the a.c. circuits (transformer, heater circuits). The hum component of frequency $2f_m$ is produced by the ripple in the output voltage of the full-wave rectifier. Other hum components of frequencies $3f_m$, $4f_m$, etc. are small and can be disregarded. Therefore, it is sufficient to have two narrow-band filters connected to the amplifier output, which single out voltages with frequencies f_m and $2f_m$.

As can be seen from Fig. 64, connected to the input of the amplifier is resistor R_{source} equal to the internal re-

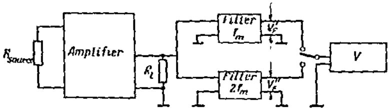


Fig. 64. Hookup for measuring hum components

sistance of the signal source which feeds the amplifier in the real circuit, and to the output of the filters voltmeter V is connected. The geometrical sum of the voltages at the

filter outputs determines the hum level of the audio frequency amplifier

$$V_F = \sqrt{(V'_F)^2 + (V''_F)^2}$$

Amplitude and Frequency Response

The hookup for measuring the amplitude and frequency response of an AF amplifier is shown in Fig. 65*a*. The amplitude response is measured on a medium frequency of the

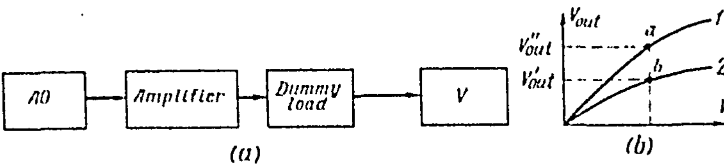


Fig. 65. Testing audio frequency amplifier

(*a*) hookup for measuring amplitude and frequency response; (*b*) amplitude responses for extreme positions of gain control

band. The input voltage of the amplifier is set equal to the sensitivity of the amplifier, and then this voltage is increased until the output voltage is equal to 1.2 to 1.5 of the nominal output voltage. The results of the measurements are used to plot the dependence $V_{out} = f(V_{in})$ (Fig. 65*b*). If a gain control is provided, the amplitude response is usually measured at both the maximum (curve *1*) and minimum (curve *2*) gain settings. The limits of gain control are characterized by the ratio $\frac{V''_{out}}{V'_{out}}$ at one and the same input voltage which is selected so that points *a* and *b* are on the linear section of the amplitude response curve.

On the basis of the amplitude response, it is possible to determine the amplification factor (gain). It is equal to the coordinates of any point on the amplitude response curve

$$K = \frac{V_{out}}{V_{in}}$$

Within the linear section of the amplitude response curve the gain remains the same for any point of this section.

For measuring the gain of an amplifier stage, the following method is recommended: the voltage of the generator is applied to the output of the given stage (points *bb* in Fig. 66). At a generator voltage of V'_{gen} the voltage at the amplifier output (points *cc*) is noted. Then the generator is connected

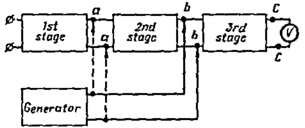


Fig. 66. Measuring amplification gain of amplifier stage

to the input of the given stage (points *aa*) and a generator output voltage V''_{gen} is set at which the former amplifier voltage is obtained. The gain of the stage

$$K = \frac{V'_{gen}}{V''_{gen}}$$

At first glance it may seem that it would be simpler to apply the generator voltage to the input of the given stage and the voltmeter to its output, and to determine the gain from the known input voltage (equal to the output voltage of the generator) and the stage output voltage. But in this method of measuring, the input resistance of the voltmeter is connected in parallel to the anode load of the stage, which may significantly change the operating conditions of the stage. This shortcoming does not exist in the method considered above.

At high signal amplitudes, the direct proportionality between the input and output voltages is violated. This means that the shape of the amplified signals is distorted. For example, with a sinusoidal input signal, the output signal will have a flat top, and there will appear output frequencies that were not applied to the input. The appear-

nce of new frequencies at the output of an amplifier or other circuit is always due to nonlinearity of the characteristics of the circuit elements, and therefore distortion of signal shape due to nonlinearity of the amplitude response is known as nonlinear distortion.

With correct selection of the operating point and low amplitudes of the amplified signals, an electronic valve and a transistor operate as linear elements, since the operating section of their volt-ampere characteristics remains linear. At high signal amplitudes, intense nonlinear distortion may appear due to anode current cutoff, the appearance of grid current, the transition of transistors to saturation conditions, and so on. At high signal amplitudes, nonlinear distortion may also be caused by transformers.

Nonlinear Distortion

The degree of nonlinear distortion is characterized by the *nonlinear distortion factor*

$$\gamma = \frac{\sqrt{V_2^2 + V_3^2 + V_4^2 + \cdots}}{V_1} \, 100\,\%$$

where V_1 = voltage of the first harmonic at the amplifier output (the frequency of the amplified sinusoidal signal)

V_2, V_3, V_4 = voltages of the higher harmonics

The presence of intense nonlinear distortion can be detected with the aid of an oscillograph. Having applied the given sinusoidal voltage to the amplifier input, it is necessary to connect the oscillograph by turns to the outputs of the amplifier stages, beginning with the last stage. If the shape of the output voltage is sinusoidal, there is no intense nonlinear distortion. If there is noticeable distortion of the output signal, it is necessary to find the stage the shape of whose output signal is distorted with the input signal not distorted. It is in this stage that the fault should be sought (wrongly selected operating conditions, faulty electronic valve or transistor, mistake in wiring, etc.).

With the aid of an oscillograph, it is possible to dis-
cover nonlinear distortion with a distortion factor exceed

ing 10 per cent; it is practically impossible to determine the value of this factor with the required precision.

To measure nonlinear distortion use is made of harmonic analyzers or nonlinear distortion meters. The amplifier input is supplied with a sinusoidal voltage of a given amplitude from an audio oscillator, and a harmonic analyzer or a nonlinear distortion meter is connected to the amplifier output in parallel to its load. With the aid of the harmonic analyzer, it is possible to measure the amplitude of each of the harmonics and then, by means of calculation, to determine the nonlinear distortion factor. It is required in those cases, when one must know the relationship between the harmonic amplitudes. The nonlinear distortion meter provides a direct reading of the distortion factor from its scale and allows for high measuring productivity but does not show which of the harmonics has the highest amplitude.

Frequency response. This characteristic of an audio frequency amplifier can be measured either point by point or with the aid of a frequency response meter according to the procedure described in Sec. 6.1.

In view of the high ratio between the maximum and minimum frequencies of the AF amplifier band, it is inconvenient to plot the frequency response curve on a linear scale. For example, if the AF amplifier covers a band of from 50 hertzes to 10 kilohertzes with a linear scale of 1 millimetre per 10 hertzes, it will be necessary to extend the horizontal axis to 1 metre.

To eliminate this difficulty, a logarithmic scale is used for plotting (Fig. 67), i.e., the horizontal axis is divided

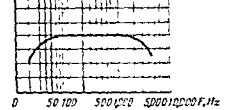


Fig. 67. Logarithmic frequency scale

into sections proportional to the logarithm of the frequency. Along the vertical axis, the amplification gain can be plotted on a linear scale.

To avoid nonlinear distortion, the input voltage of the amplifier should be selected so that on a medium frequency of the band the output voltage of the amplifier approximately corresponds to the middle of the linear section of the amplitude response curve.

If the amplifier is provided with a bandwidth control (tone control), the frequency response is measured with the tone control in the extreme and the middle positions.

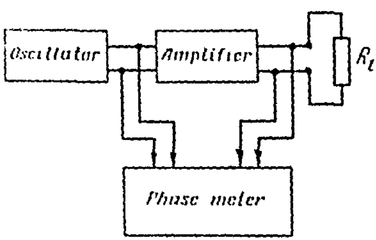


Fig. 68. Hookup for measuring phase characteristic

Phase characteristic. In view of the inclusion in an amplifier circuit of reactive elements (input and output capacitances of valves and transistors, inductances of correction coils, coupling capacitors, inductances of transformer windings), there is a phase shift between the voltages at the input and the output of the amplifier. What is more, the phase angle depends on the frequency. In amplifying audio oscillations, phase distortion of the signal is unimportant, because it cannot be detected by the human ear. In audio amplifiers designed for other purposes, phase shifts may play a significant role.

To measure the phase characteristic, use is made of the hookup shown in Fig. 68. Special instruments designed for measuring phase shift are used as phase meters or measuring circuits are hooked up in which various methods of measuring phase angles are used. Usually oscillographic methods of measuring phase angle are chosen. They are dealt with in the study of radio measurements.

6.3. RADIO FREQUENCY AMPLIFIERS

Measurement circuit. The operation of a radio frequency amplifier is greatly affected by its input resistance. The

input resistance affects such important parameters of an RF amplifier as its noise factor and the stability of its operation. Therefore, it is necessary to reproduce as completely and precisely as possible the realistic conditions of operation of an RF amplifier with respect to its input. If the input of an RF amplifier in a real circuit is connected to an antenna, the oscillator should be connected to the amplifier input via a coupling circuit which together with the internal resistance of the oscillator forms a dummy antenna. If in a real circuit (Fig. 69) voltage is applied to an RF amplifier from an oscillator with internal resistance R_o, and in testing use is made of an oscillator with internal resistance R_1, the coupling resistance should be

$$R_c = R_o - R_1$$

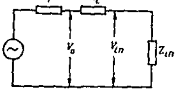


Fig. 69. Reproducing realistic input load of RF amplifier

If the RF amplifier has a balanced input, i.e., the input terminals have the same potential with respect to the chassis, the output voltage of the oscillator also should be balanced, or there should be a balancing circuit between the oscillator and the RF amplifier for converting the unbalanced voltage of the oscillator into a balanced voltage. In those cases when the coupling circuit provides matching of the internal resistances of the oscillator and the RF amplifier, it is known as a *matching circuit* (device). The output resistance of the matching circuit should be equal to the input resistance of the RF amplifier.

The matching circuit introduces a certain attenuation of the signal, i.e., the voltage at the output of the matching circuit is less than the output voltage of the oscillator. This should be taken into account when determining the amplitude of the voltage at the amplifier input. For this the output voltage of the SSG should be reduced as much as the signal is attenuated by the coupling circuit:

$$V_{in} = kV_o$$

where V_{in} = voltage at the amplifier input

V_o = voltage at the SSG output
k = attenuation factor introduced by the coupling circuit

The parameters and characteristics of an RF amplifier are measured by the same methods as have been examined in Sec. 6.1. The SSG and the voltmeter should be designed for operation within a range of frequencies well exceeding in both directions the passband of the amplifier.

When making use of frequency response meters, the frequency sweep, i.e., the amplitude of the frequency deviation, should considerably exceed the amplifier passband.

It is especially important that the work place for adjusting and testing RF amplifiers be correctly hooked up. All the connections between the amplifier and the measuring instruments, as well as the connections of the coupling circuits should be made with coaxial cables. The coupling circuit located between the oscillator and the amplifier should be reliably shielded, and its chassis should be reliably connected to the shields of the connecting cables.

Let us examine the characteristic properties of adjusting RF amplifiers.

Adjusting RF amplifiers. After checking the circuitry of the RF amplifier and the operating conditions of the valves or transistors against resistance and voltage charts, it is necessary to ascertain that there is no parasitic oscillation in the amplifier. For this a voltmeter should be connected to the amplifier output. The presence of a voltage at the amplifier output with no voltage at its input indicates that there is parasitic oscillation. To find the stage where the parasitic oscillation develops, it is necessary to short-circuit one by one the inputs of the stages, beginning with the first one. The disappearance of the voltage at the output of the RF amplifier indicates that the source of parasitic oscillation is located in the preceding stage or in the stage whose input has been short-circuited.

The causes of parasitic oscillation may be ill-arranged circuitry, absence of a contact between a shield and a chassis, etc.

Having checked the operating conditions and ascertained that there is no parasitic oscillation, alignment of the tuned circuits can be undertaken.

Alignment is begun with the last stage of the RF amplifier. A valve voltmeter is connected to the output of the RF amplifier, and an RF oscillator, to the input of the last stage. The oscillator dial is set to the frequency to which the last stage should be aligned (tuned), and the slug in the coil of the RF amplifier tuned circuit is turned to obtain maximum reading of the voltmeter. Then the anode tuned circuit of the last stage is shunted by a sufficiently low resistance to obtain a fairly flat frequency response in the stage. After this the output voltage of the oscillator is applied to the input of the last but one stage. The voltmeter remains connected to the output of the RF amplifier.

Having set the oscillator frequency equal to that of the preceding stage, adjust its coil slug to maximum reading of the voltmeter. Alignment of all the subsequent stages all the way to the first is done in the same way.

After tuning each stage to the appropriate frequency, disconnect all the shunting resistors and check the frequency response of the amplifier. For this the voltage of the oscillator is applied to the amplifier input and maintained at a constant amplitude, while measuring the gain of the amplifier over a range of frequencies.

This procedure for aligning an RF amplifier does not change when a frequency response meter is used. Only in this case the oscillograph of the meter is used instead of the voltmeter, and its wobbulator, instead of the oscillator. The output of the frequency response meter is reconnected from the input of the last stage in the direction of the preceding stages, just as the output of the oscillator was reconnected from stage to stage.

Measuring the noise factor. The noise of valves, resistors, transistors, and other components, caused by the chaotic motion of charges, produces a noise voltage. Of especial significance is the noise generated in the first and second stages of the amplifier, because it is amplified by the following stages. The noise of the subsequent stages has little effect because the level of the signal, amplified by the first stages, is higher compared to the noise voltage of these stages.

The noise voltage contains an infinite number of compo-

nents which form a continuous and infinitely broad frequency spectrum. But at the amplifier output the noise frequency spectrum has a limited width, because the amplifier passes only those components of the noise spectrum, which lie within the limits of its passband.

Let us imagine an ideal, noiseless amplifier, i.e., an amplifier at whose output there is no noise when its input is short-circuited. If such an amplifier is supplied from a signal source, the internal resistance of this source R_i will produce a noise. Consequently, if the signal source is switched off, but its output is connected to the amplifier input, even at the output of an ideal amplifier noise will develop, the power of which depends on the amplifier gain and on the power of that part of the noise of the signal source resistance which falls within the passband of the amplifier.

It has been proved that if the internal resistance of the signal source is equal to the input resistance of the amplifier, the noise power at the input of an ideal amplifier

$$P_{n.id.in} = kT_0 \Delta f$$

where k 1.38×10^{-23} j/deg = the Boltzmann constant
T_0 = absolute temperature
Δf = passband of the amplifier

The noise power at the input of an ideal amplifier does not depend on the frequency to which the amplifier is tuned, or on the resistance of the source (and the input resistance of the amplifier which is equal to it). $P_{n.\,id.\,in}$ is proportional to the temperature due to the increase in the chaotic motion of the charges and proportional to the passband, because an effect is exerted only by that part of the noise spectrum, which is amplified by the amplifier.

Let us consider an ideal and a real amplifier as linear, i.e., that the voltage and power at the amplifier output are in direct proportion to the voltage and power at the amplifier input.

In a real amplifier, the noise power at the output is produced not only due to the noise developed by the internal resistance of the signal source, but also due to the noise developed in the components of the amplifier itself. Therefore, the noise power at the output of a real amplifier is greater than that at the output of an ideal amplifier. The

level of noise introduced by the amplifier itself is characterized by the ratio of the noise power at the output of a real amplifier to the noise power at the output of an ideal amplifier, i.e., the same kind of amplifier only one that does not introduce noise. The ratio of the above noise powers is known as the *noise factor*

$$K_n = \frac{P_{n\,out}}{P_{n\,id\,out}}$$

where $P_{n\,out}$ is the noise power at the output of a real amplifier.

Since the amplifier is linear, the ratio of noise powers at the amplifier output is equal to the ratio of noise powers at its input, therefore the noise factor can also be expressed by the ratio:

$$K_n = \frac{P_{n\,in}}{P_{n\,id.in}}$$

Here by $P_{n.in}$ one should regard the equivalent power of an imaginary noise source acting on the amplifier input and developing at its output the same noise power $P_{n.out}$ which is actually developed by both the internal resistance of the signal source and the components of the amplifier itself.

For measuring $P_{n.in}$ let us make use of the hookup shown in Fig. 70. Let us switch off the SSG and leave it connect-

Fig. 70. Hookup for measuring noise factor

ed to the amplifier. The internal resistance of the SSG and the noise of the amplifier will develop at the amplifier output a noise, the power of which $P_{n.out}$ can be determined from the reading of a square-law voltmeter, knowing the resistance of the load

$$P_{n\,out} = \frac{V^2_{n\,out}}{R_l}$$

The passband of the square-law voltmeter should be broader than that of the amplifier.

Let us switch on the SSG and set at its output such a voltage V_{SSG} that the power at the amplifier output will double, i.e., become equal to $2P_{n.out}$. As, according to the given conditions, the amplifier is linear, then the power at its input also doubles and becomes equal to $2P_{n.in}$. Consequently, we have added an equal power P_{SSG} to the equivalent power $P_{n.in}$ ($P_{SSG}=P_{n.in}$).

The noise factor can be determined from the equation

$$K_n = \frac{P_{n.in}}{P_{n.id.in}} = \frac{P_{SSG}}{kT_0\,\Delta f}$$

Amplitude and frequency responses of an RF amplifier. The procedure for measuring the amplitude and frequency responses of an RF amplifier does not differ from that described in Sec. 6.1. Let us only note a few specific features.

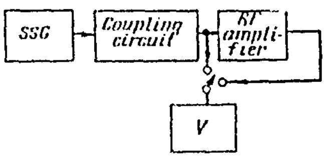


Fig. 71. Hookup for measuring attenuation factor of coupling circuit

For determining the attenuation factor introduced by the coupling circuit, let us make use of the hookup shown in Fig. 71. The attenuation factor

$$K_{at} = \frac{V_{c.out}}{V_{SSG}}$$

where $V_{c.out}$ is the voltage at the output of the coupling circuit.

To determine the amplification factor of the amplifier under investigation, it is necessary to measure the voltage at the amplifier output and to read the output voltage of the SSG. The amplification factor is determined from the equation

$$K = \frac{V_{out}}{V_{SSG}\,K_{at}}$$

The test equipment for measuring amplitude and frequency characteristics should correspond to the parameters

of the RF amplifier under test both in frequency range and in internal resistance. It is desirable that the internal resistance of the oscillator be equal to the input resistance of the RF amplifier, and the input resistance of the voltmeter be sufficiently high. If the RF amplifier is loaded by a detector, it is better to connect the voltmeter to the detector output and to set a definite depth of modulation on the SSG.

Nonlinear distortion. For measuring nonlinear distortion, use is made of the hookup shown in Fig. 72.

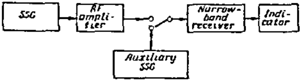


Fig. 72. Hookup for measuring nonlinear distortion of RF amplifier

The narrow-band receiver is tuned to the frequencies of the harmonics of the RF amplifier output signal. The frequency and amplitude of the harmonics are determined from the dial of the auxiliary standard signal generator. Having tuned the narrow-band receiver to one of the harmonics of the RF amplifier output voltage and having obtained a certain reading of the indicator connected to the output of the narrow-band receiver, it is necessary to connect the auxiliary SSG. The SSG should be tuned to the frequency of the narrow-band receiver so as to obtain maximum reading of the indicator, and the output voltage of the auxiliary SSG should be set so as to obtain the previous reading of the indicator (the same as when the narrow-band receiver was tuned to a harmonic of the RF amplifier). The voltage obtained at the output of the auxiliary SSG is equal to the amplitude of the given harmonic.

Next the narrow-band receiver should be tuned to another harmonic and all the above measurements repeated. The nonlinear distortion factor is determined from the relationship:

$$\gamma = \frac{\sqrt{V_2^2+V_3^2+\dots}}{V_1}\,100\,\%$$

here V_1, V_2, V_3... are the voltages of the harmonics.

6.4. PULSE AMPLIFIERS

The quality of pulse amplifiers can be evaluated by the same parameters and characteristics as continuous oscillation amplifiers. However, the measurement of the frequency response of pulse amplifiers requires much time, since they have an exceedingly broad passband (from 20-50 hertzes to units and even tens of megahertzes). Most existing generators do not possess such a frequency range, therefore in measuring frequency response point by point it is usually necessary to use two generators: an audio and a radio frequency generators.

In practice, the quality of pulse amplifiers is widely evaluated by their transient response. By *transient response* is meant how the output voltage of an amplifier depends on an input voltage having the shape of an instant voltage jump (Fig. 73*a*). To measure transient response use is made of special combination instruments, i.e., transient response meters, which contain a pulse generator and a pulse oscillograph. The output of the pulse generator is applied to the input of the amplifier under test, and the input of the pulse oscillograph, to its output.

Transient response can also be measured by using a pulse generator and a separate pulse oscillograph (Fig. 73*b*).

When a square pulse is fed into an amplifier (Fig. 73*c*) a distorted pulse develops at its output (Fig. 73*d*). The leading edge of the pulse is drawn out because the input and output capacitances of the stages do not charge instantaneously. The higher these capacitances, the greater the edge is drawn out.

Discharging of these capacitances does not take place instantaneously either, therefore upon the input voltage disappearing almost instantaneously, the amplifier output voltage falls off relatively slowly: the trailing edge of the pulse is drawn out. The time during which the voltage is building up is known as the *pulse rise time*, and the

during which the voltage falls, as the *pulse decay time*. The duration of the leading edge t_l and the duration of the trailing edge t_t are conventionally taken as the time during which the edge changes in amplitude from 0.1 to 0.9 V_m (V_m is the pulse amplitude).

The pulse top at the amplifier output has a certain droop δ_L (Fig. 73e) which is due to the charging of the coupling

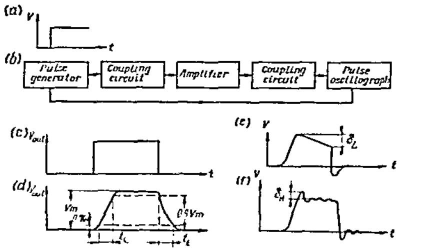


Fig. 73. Measuring transient response of amplifier

(a) input voltage; (b) hookup for measuring; (c) pulse at amplifier input; (d) distortion of pulse leading and trailing edges; (e) pulse droop; (f) curve showing effect of correction coil

capacitors C_g in the amplifier (see Fig. 61a). These capacitors are connected in series with the grid resistors of the following stage. As these capacitors charge, the pulse voltage at the input of the following stage decreases by the voltage drop across the coupling capacitor.

The lower the capacitance of the coupling capacitor, the faster it charges, and the greater the pulse droop. The value of δ_L can serve as a measure of the distortion in the region of lower frequencies for it is on low frequencies that the coupling capacitor possesses the highest resistance (reactance).

In pulse amplifiers incorporating correction of frequency

esponse in the region of higher frequencies (see Fig. 61a), pulse spike δ_H or a series of oscillations at the beginning and the end of the pulse often appears (Fig. 73f). This is due to the development of inherent damped oscillations in the correction coils at moments of sharp change in the current, i.e., at the beginning and the end of the pulse. In order to reduce the spike, it is necessary to reduce the Q-factor of the correction coil by shunting it with a sufficiently low resistance or by increasing the resistance of anode load R_a.

There is a close relationship between the transient and frequency responses of an amplifier. Frequency distortion in the region of higher frequencies also depends on the input and output capacitances of the stages. Corresponding to an increase in the frequency distortion factor on the higher frequencies is an increase in the rise time of the transient response. Corresponding to an increase in the frequency distortion factor in the region of lower frequencies is an increase in the pulse droop δ_L.

Thus, the transient response characterizes sufficiently well the passband of a pulse amplifier.

The pulse amplitude at the input and output of the amplifier is measured with the aid of a pulse oscillograph provided with a pulse amplitude calibrator.

To measure transient response and to determine the parameters of pulse amplifiers, it is necessary to choose th correct measuring equipment. The rise and decay time o the output pulse produced by the generator should be a least several times less than the expected rise and deca time of the pulse at the amplifier output, and the pul should have no droop or spikes.

The pulse oscillograph should have a vertical-defl tion amplifier possessing a passband exceeding several mes the passband of the amplifier under investigatior

The duration of the generator output pulse should variable within a wide range: for investigating leading trailing edges, short pulses with very steep edges ar quired, and for investigating the lower frequency res of an amplifier, i.e., for observing the pulse droop. ses of sufficiently long duration are required.

More precise measurement results can be obtai

allowance is made for the defects in the generator output pulse and the distortion introduced by the oscillograph. For this it is necessary to measure with the oscillograph the duration of the pulse leading edge t'_l and the pulse droop δ'_L by applying directly to the oscillograph the output pulse of the pulse generator. Then measure the duration of the pulse leading edge (or rise time) t''_l and the pulse droop δ''_L of the amplifier output pulse. The rise time of the amplifier transient response

$$t_l = \sqrt{t''^2_l - t'^2_l}$$

and the pulse droop

$$\delta_L = \delta''_L - \delta'_L$$

The input and output pulses of the amplifier under investigation can be checked with the aid of a two-beam pulse oscillograph. The pulse at the amplifier input is applied via the oscillograph amplifier to one pair of vertical-deflection plates, and the output pulse of the amplifier, to the other pair. Images of the input and output pulses appear simultaneously on the screen of the two-beam oscillograph. By bringing the amplitudes of the two pulses to the same level, it is easy to compare their shapes.

The parameters and characteristics of radio pulse amplifiers can be determined by the same methods as those of video pulse amplifiers. A commonly used hookup for testing radio pulse amplifiers is shown in Fig. 74a.

The input of the amplifier under test is supplied via a coupling circuit with signals from a pulse-modulated radio frequency generator. The generator is set, according to its dial, to the middle frequency of the amplifier passband, and its internal pulse modulation is switched on. The radio (RF) pulses (Fig. 74b) are applied from the input or output of the amplifier to the oscillograph via a detector that produces the envelope of the radio pulse (Fig. 74c).

Comparison of the envelopes of the radio pulse at the input and output of the amplifier makes it possible to evaluate the distortion of the pulse shape that is introduced by the amplifier by the methods examined when analyzing video amplifiers.

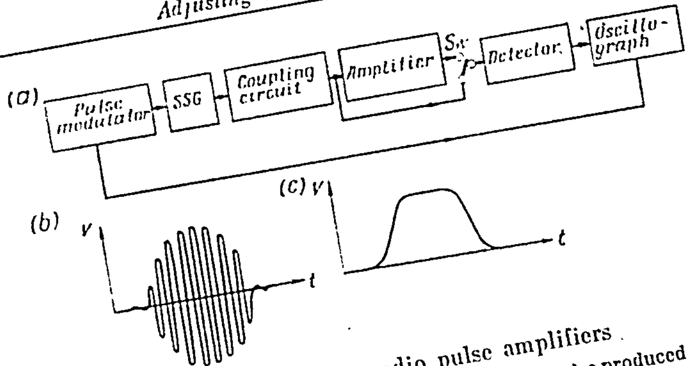


Fig. 74. Testing radio pulse amplifiers

(a) measurement hookup; (b) RF pulse; (c) envelope of RF pulse produced by detector

For certain types of radio-pulse amplifiers the time it takes the radio pulse to pass through the amplifier is highly important, i.e., the time that the beginning of the output pulse is delayed with respect to the beginning of the pulse at the amplifier input. The *delay time* is determined by one of the following methods.

It is possible to use the hookup shown in Fig. 74*a*. In this case the oscillograph sweep is triggered by the pulse modulator of the generator. Switch *Sw* connects first the input and then the output radio pulses. The corresponding video pulses develop at the detector output. The pulses can be seen on the oscillograph screen displaced with respect to the beginning of the sweep by times t_1 and t (Fig. 75). The delay time is equal t their difference

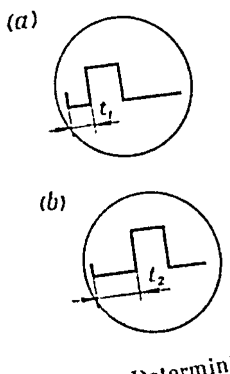


Fig. 75. Determining delay time

a) input pulse; (b) output pulse

$$t_{del} = t_2 - t_1$$

Another method makes use of hookup shown in Fig. 76*a*. Vi pulses are supplied to the ampli input from a generator. At the ment of a sharp jump in the vol

damped oscillations develop in the tuned circuit of the first amplifier stage; they are amplified by the following stages of the radio pulse amplifier. By switching the input and output of the amplifier as before, we obtain damped oscillations on the oscillograph screen, the beginning of which is shifted by time $t_2 - t_1$ (Fig. 76*b* and *c*),

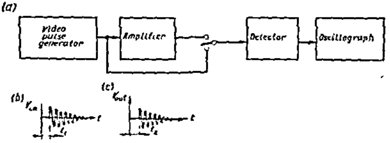


Fig. 76. Determining pulse delay time with the aid of video pulse generator

(a) measurement hookup; (b) and (c) oscillograms of voltages at input and output of amplifier

where t_2 is the time from the beginning of the sweep to the beginning of the damped oscillations at the amplifier output, and t_1 is the time from the beginning of the sweep to the beginning of the input pulse.

Review Questions

1. What are the purpose of various types of amplifiers and the requirements they must meet?
2. What are the methods of measuring frequency response? What are the advantages and shortcomings of each of them?
3. What do you know about adjusting and checking parameters of (a) audio frequency amplifiers, (b) radio frequency amplifiers, and (c) pulse amplifiers?

CHAPTER VII

Adjusting and Testing Communication Radio Transmitters

7.1. GENERAL

The transmitting circuits of radio communication equipment are designed for radiating into surrounding space radio frequency energy containing certain information.

A transmitter may transmit communications on fixed radio (carrier) frequencies or possess a continuous band within which it is possible to set any carrier frequency.

The block diagram of the communication transmitter in Fig. 77 includes:

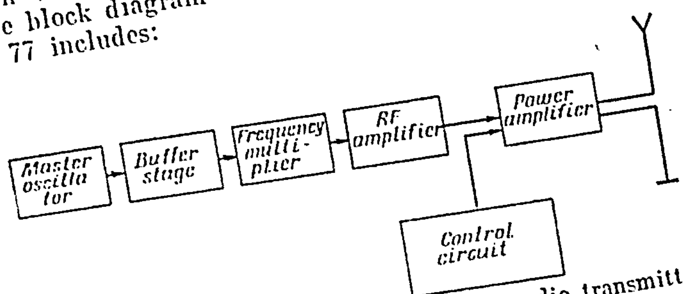


Fig. 77. Block diagram of communication radio transmitter

a master oscillator which produces a radio frequency [stage] (a low-power self-excited oscillator with a contin[uous] frequency band or fixed frequencies);

a buffer stage which is actually an RF amplifier [ope]rating without grid currents and therefore lightly lo[ading] the master oscillator; its main function is to weake[n the] coupling between the master oscillator and the fol[lowing] stages so that variations in their operating conditi[ons do] not affect the frequency;

a frequency multiplier which has two basic functions: increasing several times the frequency of the voltage produced by the master oscillator and weakening the coupling between the master oscillator and the following stages;

a radio frequency amplifier, or driver stage, which steps up the voltage and power of the RF oscillations to the level necessary for obtaining the maximum power from the output stage;

a power amplifier which is coupled to the antenna of the transmitter and supplies the RF power into it;

a control circuit which serves for superimposing the required information on the radio frequency oscillations.

Information can be transmitted by radiating radio frequency pulses of various duration and repetition frequency. In this case the transmitter is opened and cut off by the control circuit in such a way that the order of the radiated RF pulses contains the coded information. Such operation is typical for the case of transmission of telegraph signals and the work of SHF pulse transmitters. In this case the control circuit is known as a pulse modulator or a keyer.

The control circuit may affect the amplitude or frequency of the RF oscillation, and in this case the transmitted information is contained in variations of the amplitude or of the frequency of the radio frequency oscillations.

The master oscillator and the buffer stage are often combined into a single unit called the exciter.

The widely differing fields of application, of operating conditions and of the nature of operation of transmitting circuits have led to a wide variety in the types of transmitters manufactured. They can differ in power, mode of operation (telegraph, telephone, phototelegraph, pulse transmission), their wave band, ability to be moved about (stationary, i.e., designed for prolonged operation without being moved, portable, car, etc.), field of application (trunk communication, local communication, radio broadcasting, radio navigation, etc.), and in a number of other characteristics.

Transmitters of different types are to meet different electrical, operational, and design requirements.

The most characteristic parameter of a transmitter which determines the range of the transmitting radio station

and the reliability of radio communication is the power output of the transmitter. By *power output* is meant that power which the transmitter supplies into the antenna. Among the other principal parameters of a transmitter are the frequency range (or list of fixed frequencies), calibration accuracy, frequency stability, and also the type of modulation.

By *frequency range* is meant the frequencies interval within which any carrier frequency can be set. The range can be divided into bands. Frequency is set according to a dial.

By *frequency setting accuracy* is meant the accuracy with which the carrier frequency of the transmitter corresponds to the frequency set on the dial. By *frequency stability* is meant the constancy of the frequency calibration under the action of external factors and the flow of time. For example, if the stability of the transmitter is equal to 0.001 per cent per hour, this means that the frequency drift of the transmitter under the given operating conditions will not exceed 0.001 per cent per hour.

The requirements to be met by modulation determine that depth of modulation (amplitude or frequency) at which the distortion of the transmitted signal does not exceed the permissible value.

7.2. CHECKING TRANSMITTER FOR OPERABILITY

General requirements and procedure. Adjustment of a transmitter demands strict observation of safety rules. The inclusion of high-power stages and the presence of high voltages calls for great care and strict observance of the sequence of all operations specified in the technological chart or the adjustment instructions, the rules for switching supply sources on and off, the connection of measuring instruments, the use of protective means, etc. Violation of these rules may cause accidents and damage to expensive equipment.

Before switching on the supply source, it is necessary to examine the transmitter externally, to check whether all the connections in it have been made correctly, to check the resistance and electrical strength of the insulation.

Attention should be paid to the condition of coatings, to the absence of dirt on the surfaces of insulating materials, to checking for the absence of jutting corners of components and for burrs, which all facilitate flashover and breakdown by high voltage.

After external examination, the various low-voltage circuits of the transmitter are checked with the high voltage switched off. Modern transmitters have provision for the switching-on of the high voltage only in a certain period of time after the switching-on of the heater voltage. This is done with the aid of a time relay. Preliminary heating of the heaters or filaments is necessary so as to prevent destruction of the cathodes of high-power valves. It is also necessary to check the time from the switching-on of the heater voltage to the operation of the time relay.

Transmitters incorporate various devices and circuits designed for preventing electric shock. The interlock system is made in such a way that opening of a door or disconnection of panels automatically switches off the high voltage. There are also discharging devices that serve for discharging high-voltage capacitors when various units are removed from the transmitter rack.

All the above circuits and the reliability of operation of the protective devices should be carefully checked.

Next the system for protecting transmitter components from overloads is checked. This system includes various relays and breakers which automatically disconnect the corresponding circuits in case of faults that can cause damage to high-costing assemblies of the transmitter. The operation of the various interlocking, protective, and control elements is monitored with the aid of signal lamps of various colours. In addition the control, interlocking, and signalling (CIS) system may include various circuits for monitoring cooling systems, switching on standby units and components, etc.

After checking the CIS system, checking of the supply sources is undertaken. First the heater circuits are switched on, then the bias circuits, and only after that a reduced high voltage. In many transmitters this sequence of switching-on is done automatically by devices included in the CIS system. The presence of normal supply source voltages

is usually checked with the aid of built-in measuring instruments (meters).

Such meters may not be included in low-power transmitters, therefore use is made of universal measuring instruments, the interlock contacts being shorted preliminarily. In such cases the safety rules should be especially strictly observed. The instruments should be connected with the high voltage switched off, protective measures should be adopted, no unauthorized persons should be in the vicinity of the equipment being adjusted.

Transmitter block diagram. Let us consider the checking of a transmitter for operability, using as an example the KV-5 transmitter, the block diagram of which is shown in Fig. 78.

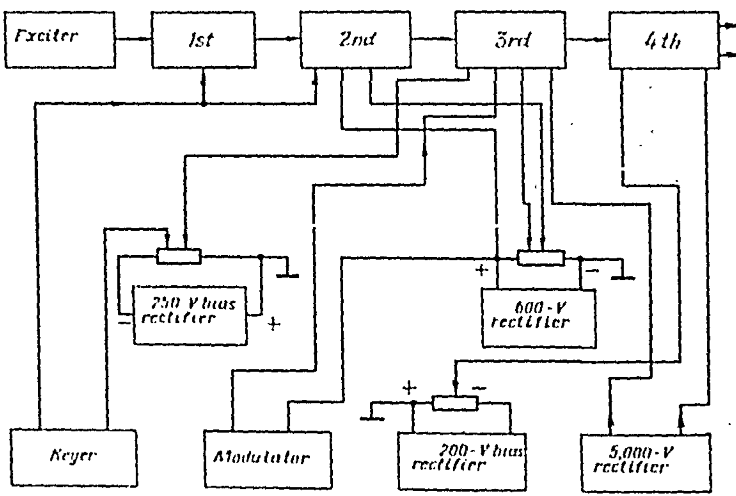


Fig. 78. Block diagram of short-wave transmitter, type KV-5

Its radio frequency section contains an exciter and amplification stages 1, 2, 3, and 4. Telegraph keying is obtained by supplying the control grids of the 1st and 2nd amplification stages with a high negative voltage when the telegraph key is released and with a normal voltage

when the key is depressed. The bias source is a rectifier producing a voltage of —250 volts.

In telephone operation, sound oscillations converted into an audio frequency voltage are amplified by the modulator and supplied to the suppressor grids of the 3rd amplification stage valves, causing the amplitude of the RF oscillations to change according to the shape of the transmitted signal.

The 4th stage — the power amplifier, supplies the antenna of the transmitter.

The anode circuits of the 3rd and 4th amplification stages are supplied from a high-power rectifier of 5,000 volts, the anode voltage of the 3rd stage valves being 2,500 volts, as it is taken from the centre-point of this rectifier. Provision is also made for applying 2,500 volts to the anodes of the output valves, this being necessary during tuning of the transmitter.

The anode circuits of the 1st and 2nd stages and the output stage of the modulator are supplied from a 600-V rectifier. The same rectifier is used for supplying the screen grids of the 2nd and 3rd stages. Bias voltage for the output stage valves is supplied by a rectifier producing a voltage of —200 volts. Negative voltage for the control and screen grids of the 3rd stage is supplied by a rectifier producing a voltage of —250 volts.

In addition to the four main rectifiers shown in the block diagram, the transmitter includes five auxiliary rectifiers intended for supplying the anode and screen circuits of the modulator and keyer and also the control grids of the 1st and 2nd stage valves and the screen grid of the 1st stage valve.

The heater circuits are supplied by step-down heater transformers.

Before checking the operability of the transmitter as a whole, the operability of each rectifier, modulator, keyer, and exciter is checked, with the exciter being fully tuned and checked for all basic parameters, including checking for frequency stability.

Transmitter protection. It is necessary to check thoroughly all the elements that serve to protect the transmitter from overloads and short-circuits for normal operation.

To provide protection against short-circuits, the KV-5 transmitter incorporates electromagnetic relays. In the case of short-circuits in the load circuits of the high-power rectifiers, the electromagnetic relay operates instantaneously, disconnecting the supply circuit.

Protection against overloads is provided by thermal relays. These relays do not react to brief fluctuations in the load. They operate in case of a 1.5-fold overload lasting 40-60 seconds, disconnecting the supply circuit in cases of relatively prolonged increases in load current.

It is possible to adjust the tripping current of the relay within limits of up to 800 per cent of the rated current.

The valves of the 3rd and 4th stages of the radio frequency channel are protected with the aid of relays included in the cathode circuits of the valves. In case of overloads exceeding 200 per cent or of breakdowns in the anode circuits, these relays disconnect the high voltage. The high-power 5,000-V rectifier is provided with protection in both the d.c. and a.c. circuits. The low-power rectifiers are provided with protection by thermal and over-current relays in the a.c. circuit. In the d.c. circuit they are protected by fuses.

Monitoring of the bias at the transmitting valves of the 3rd and 4th stages and monitoring of normal operation of the —200-V and —250-V bias rectifiers are provided by bias relays.

These relays are connected to the bias potentiometers as shown in Fig. 79. In the absence of bias voltage these relays operate and disconnect the high voltage.

A number of protection elements are operated via the CIS system.

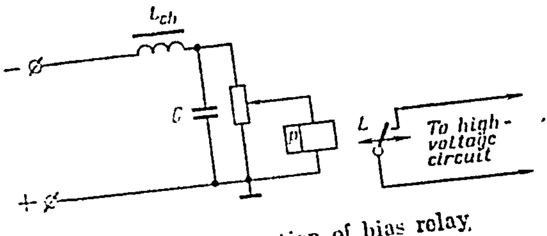


Fig. 79. Connection of bias relay.

The CIS system of a transmitter. The control, interlocking, and signalling (CIS) system provides:

the switching on and off of the transmitter with the aid of the control buttons located on the front panel;

a strict sequence of operations in switching the transmitter circuits on and off (if the sequence is violated due to a mistake of the operator or due to a fault, the CIS system will prevent electrical damage by refusing to carry out an operation that does not conform to the correct sequence);

safety of the attendant personnel (on the opening of doors, the removal of units, etc. it removes the high voltage);

signalling of normal operation and of faults.

The CIS system includes both manual and automatic transmitter supply controls.

Manual control is provided by automatic button switches which can switch on the mains power supply, the variable autotransformer, the exciter supply, the heater circuits supply, the low-power rectifiers, the CIS system supply, the fan motor which provides air cooling of the high-power valves, and other circuits.

The automatic monitoring and control organs contain an intricate system of relays and switches. Thus, when a unit is pulled out, the high-voltage breakers operate automatically. The necessary warm-up time of the thyratron and of the transmitting high-power valves is ensured by a time relay which makes the supply circuit of the high-voltage rectifiers only when a definite time has passed after the switching-on of the heater supply. Normal operation of the cooling system is automatically monitored by an airbreak contact located in an air duct of the system. The airbreak contact breaks the high-voltage supply circuit if the fan motor stops. It also prevents the switching-on of the high voltage until the fan motor is operating.

The elements of the CIS system are supplied with a relatively low voltage. The system is checked according to a strict procedure with the high voltage switched off.

Certain CIS systems have provision for monitoring the absence of breakdown of circuits to the chassis (Fig. 80). Voltmeters V_1 and V_2 are connected in series and their

junction is connected to earth. Under normal conditions each of the voltmeters reads the voltage $\frac{V_2}{2}$. In case of breakdown to earth of one of the phases of the diverging CIS system, the voltmeter connected to this phase will be

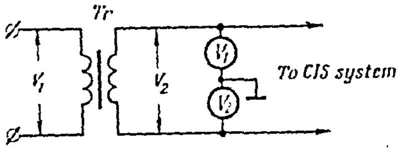


Fig. 80. Circuit for monitoring absence of breakdown in CIS circuit

shorted and will read zero. The other voltmeter will indicate all of the voltage V_2 applied to the CIS circuits.

On completing the checking of the supply and CIS systems, the tuning of the transmitter can be done.

7.3. TUNING TRANSMITTERS

When tuning transmitters the procedure is to first tune the exciter, then the intermediate stages, and finally the output stage.

Tuning the exciter. Let us consider the tuning of an exciter (Fig. 81) containing a master oscillator employing valve *V1* and a buffer stage employing valve *V2*. Tuning includes the following operations:

checking for self-oscillation throughout the band;

checking whether the frequency coverage of the band is correct and if there are several bands, checking the frequency coverage of each of them;

selection of the optimal feedback so as to obtain normal oscillation throughout the range and stability of the generated frequency;

selection of coupling with the following buffer stage;

tuning of the buffer stage.

The presence of self-excitation is checked with the aid of a neon lamp which is secured to a rod of insulating material and brought close to the exciter tuned circuit (coil).

Glowing of the neon lamp indicates the presence of radio frequency oscillations.

Having obtained oscillation, check with the aid of a wavemeter the frequency coverage of the continuous tuning band within the specified limits, by measuring the frequency at maximum and minimum settings of tuning capacitor C_1. If the required coverage is not obtained, the position of the tap connected to the capacitor (anode tap)

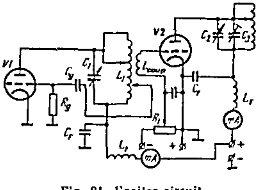


Fig. 81. Exciter circuit

should be changed until the required frequency range is obtained.

If the frequency range of the master oscillator is divided into bands, a separate coil is provided for each band. There should be no gap between neighbouring bands, i.e., the frequencies of neighbouring bands should overlap somewhat.

The amount of feedback is selected with the aid of the tap connected to the grid of valve *V1*. Having set a certain feedback, make sure that the master oscillator oscillates normally throughout the whole range. Continuously varying the frequency with the aid of capacitor C_1, observe the reading of milliammeter *mA* which measures the d.c. component of the anode current.

If the operation of the master oscillator is stable, the anode current varies smoothly, without any jumps. The presence of current jumps indicates the existence of harmful factors that disturb frequency stability. The most com-

n reasons for anode current jumps are parasitic tuned cuits whose natural frequency lies within the working quency range of the master oscillator. Such circuits arc en formed in decoupling networks out of the inductances chokes and their internal capacitances. Incorrectly se-cted decoupling chokes and by-pass capacitors may be e cause of sharp changes in the operating conditions of he master oscillator, and sometimes of complete interrup-ion of oscillation.

In the USW range, parasitic oscillations often occur on frequencies differing greatly from the tuning frequency of the tank circuit formed by capacitor C_1 and coil L_1. Simultaneous oscillation is possible on both the working frequency and on a spurious frequency. Such spurious os-cillation is eliminated by changing the electrical parame-ters of the decoupling circuits. After this it is again neces-sary to check thoroughly the operating conditions of the master oscillator throughout the whole range, since a jump in the anode current may now appear in a different sectior of the range.

For more reliable tuning of the master oscillator, it is useful to listen to its oscillations with the aid of a regene-rative receiver. The beat note heard in the receiver should be perfectly clear. An impure note indicates instability of the master oscillator frequency and abnormal operation of the oscillator.

In addition to parasitic oscillations, impure beat notes may be caused by intermittent oscillations developing in the master oscillator due to high values of the gridleak capacitor and resistor $R_g C_g$. If the frequency of the inter-mittent oscillation is low, it can be detected by vibration of the milliammeter pointer. By selecting the parameters of the gridleak or eliminating it from the circuit, it is pos-sible to exclude intermittent oscillation.

An impure tone may also be caused by pulsation of the anode supply voltage or frequency modulation due to me-chanical loads.

A final judgement on whether the feedback has beer chosen correctly can be made on the basis of tests for fre quency stability of the exciter, the procedure for whic is dealt with in Sec. 7.4.

When selecting the coupling between the master oscillator and the buffer stage, the main consideration should be that the coupling is tight enough to obtain the necessary amplitude of RF oscillations in the anode circuit of the buffer stage and at the same time as loose as possible.

Grid bias for the buffer stage is selected with the aid of potentiometer R_1 so that to exclude the appearance of grid current. If there is no built-in meter for checking the grid current, then during adjustment a milliammeter shunted by a capacitor is temporarily connected into the grid circuit. The meter should read zero at any tuning of the master oscillator.

It should be borne in mind that the amplitude of the oscillations in the anode circuit of the master oscillator and, consequently, the amplitude of the radio frequency voltage at the grid of the buffer stage vary when the frequency is varied within considerable limits. That is why the coupling of the buffer stage to the master oscillator should be checked throughout the whole frequency range.

Modern transmitters often employ ganged tuning of the buffer stage and the master oscillator, i.e., the rotors of capacitors C_1 and C_2 are rotated by a single control. Tracking of the tuning of the master oscillator and the buffer stage is obtained in the following way. Having set the ganged variable capacitor in the fully meshed position (maximum capacitance and minimum frequency of the band) and trimming capacitor C_3 in a medium position, tune the anode circuit of the buffer stage by varying the inductance of L_2 to minimum reading of the milliammeter included in the anode circuit of the buffer stage. Then set the maximum frequency of the band and tune the circuit with trimmer C_3. These operations should be repeated several times until full tuning is obtained on both the highest and lowest frequencies of the band.

Tuning of intermediate and output stages. The intermediate stages mainly fulfil two functions: step up the power of the radio frequency oscillation to the value necessary for exciting or driving the output stage and obtaining the necessary power from it and weaken the coupling between the output stage and the master oscillator. For fulfilling the second function use is often made of intermediate stages

that operate as frequency doublers and triplers. The anode circuits of these stages are tuned to either the second or third harmonic of the oscillations fed to their grid. High-power intermediate and output stages are tuned at reduced anode voltage.

Intermediate stages are tuned one by one beginning from the exciter and proceeding towards the output stage. The anode tank (tuned) circuit of an amplifier can be tuned to minimum anode current in the given stage, maximum grid current in the following stage or maximum current in the tank circuit. In the absence of built-in meters, it is possible to temporarily connect suitable instruments, observing the rules given in Sections 3.3 and 3.4.

With each subsequent amplifier stage there is an increase in the power dissipated. To obtain sufficiently high power at a high efficiency, careful selection of the operating conditions of the stage is necessary. Conditions are selected by either varying the coupling with the preceding stage or varying the grid bias of the given stage. One can judge of the increase in the useful power developed in the given stage either by an increase in the current in the anode circuit of the given stage or an increase in the grid current of the following stage.

Special care should be taken in selecting the operating conditions of a stage operating as a frequency multiplier. A distinctive feature of frequency multiplication operating conditions is that a high excitation voltage must be applied to the grid from the previous stage and also a high bias voltage. Having tuned the multiplier tank circuit, at any bias voltage, to the second or third harmonic, it is necessary to check the correctness of tuning with the aid of a resonance wavemeter. Otherwise there may be a mistake in the tuning: tuning to a different harmonic, for example, to the third instead of the second. Optimal conditions are usually selected by varying the bias. A criterion of this is maximum current in the multiplier tank circuit. If the current obtained turns out to be insufficient, the excitation voltage must be increased and operating conditions adjusted again to maximum oscillatory power in the anode circuit.

The intermediate tank circuit of the output stage is

tuned at reduced anode voltage and with the antenna disconnected to minimum reading of the ammeter measuring the d.c. component of the anode current.

The antenna is tuned with loose coupling to the intermediate tank circuit, and then the coupling is increased till the maximum current is obtained in the antenna, after which the intermediate tank circuit is slightly retuned.

After tuning it is necessary to select the operating conditions of the output stage. This is done in the same way as in the case of the intermediate stages, until the maximum power is obtained in the antenna.

Final selection of operating conditions is carried out after checking for the absence of parasitic oscillations. In most cases parasitic oscillations become manifest during tuning. They are indicated by sharp increases in the anode current of valves, increased anode dissipation, blowing of fuses, breakdown of insulation. Parasitic oscillations often cause valves to fail. But there are also weaker parasitic oscillations which exist side by side with the working oscillations and can remain undetected during tuning. These oscillations should also be eliminated, since weak parasitic oscillations can, with prolonged operation, turn into more powerful ones capable of making the transmitter inoperative.

Detection of parasitic oscillations. The simplest way of checking is to switch off the master oscillator and then to try tuning the anode and grid circuits of the stages. If there are no parasitic oscillations, the grid currents should be equal to zero and the anode currents should not change with a change in tuning.

On the contrary, the presence of grid currents or changes in anode currents indicates the presence of parasitic oscillations, that can be checked additionally with the aid of a neon lamp. Next the frequency of the parasitic oscillations should be measured, that simplifies considerably the task of finding the cause of their development.

Parasitic oscillations on low frequencies usually develop due to the formation of oscillatory systems consisting of filter capacitors and chokes. On investigating these circuits with the aid of a neon lamp, it is possible to discover intense oscillation near one of the chokes. Self-excitation of amplifier stages on frequencies close to the work-

frequency occurs due to feedback between the anode and grid circuits of the given stage, or between more powerful stages and less powerful ones.

Impermissibly great feedback may be due to poor arrangement of the circuitry, poor screening, faults in decoupling circuits, i.e., in those circuits which are intended for weakening the coupling between the stages via the common supply source. Parasitic oscillations on frequencies exceeding the working frequencies develop due to the presence in the anode and grid circuits of short-wave and ultra-short-wave parasitic oscillatory circuits formed by the distributed capacitances and inductances of connecting wires, valve electrodes, switches, etc.

The main difficulty in combating parasitic oscillations consists in finding the oscillatory circuits taking part in the self-excitation. Knowing which circuits are to blame, it is not difficult to violate the conditions of self-excitation on the parasitic frequency by introducing damping or changing the parameters of one or another component.

Tuning a transmitter during operation does not take much time because during adjustment the operating conditions of the valves, the coupling between the stages and the parameters of the tank circuits had been selected and parasitic oscillations eliminated.

7.4. TESTING EXCITERS

The exciters of radio-transmitting circuits include a master oscillator which produces the radio frequency voltage and one or more stages which serve for weakening the effect of the transmitter load on the frequency of the master oscillator. For this purpose use is made of buffer stages, i.e., stages that operate without grid currents and of frequency multipliers. Exciters can be designed to generate one or several fixed frequencies or a band of frequencies.

The basic parameters of exciters are:

frequency range or list of fixed frequencies;

calibration accuracy of frequency dial or accuracy of fixed frequencies;

frequency stability;

pull-in band of AFC system;

output voltage;

level of parasitic oscillations, i.e., oscillations which develop in the exciter on harmonics of the fundamental frequency or on other frequencies.

When adjusting and testing exciters, it is necessary to connect either the actual load or a dummy load. The processes of adjusting exciters and checking their parameters are closely linked. For example, if the exciter frequency decreases to an impermissible degree with an increase in temperature, the adjuster must change the ratio of the capacitors in the master oscillator tank circuit, which have positive and negative temperature coefficients of capacitance.

Let us examine a few basic tests of exciters.

Frequency range. The frequency range of an exciter is checked with the aid of a resonance wavemeter. The coupling between the resonance wavemeter and the exciter should be loose so as to exclude interaction between the wavemeter and the exciter. The range is checked at its extreme frequencies, and if the range is divided into bands, then at the extreme frequencies of each band.

Oscillators of fixed frequencies are checked on each of the frequencies.

Frequency setting accuracy. This parameter is checked with the aid of a high-precision heterodyne wavemeter. The exciter under check and the heterodyne wavemeter must preliminarily be warmed up. Having set one of the given frequencies of the exciter, it is necessary to measure it with the wavemeter.

The difference between the frequency readings on the exciter dial and the heterodyne wavemeter scale $f_e - f_h$ determines the absolute error.

The relative frequency setting error

$$\gamma = \frac{f_e - f_h}{f_e}$$

where f_h = frequency reading on the heterodyne wavemeter scale

f_e = frequency reading on the exciter dial

On resetting the same frequency on the exciter dial, the measurement results may differ.

The absolute repetitive frequency setting error

$$\Delta f_r = |f_1 - f_2|$$

where f_1=reading on the exciter dial when approaching the given frequency from the side of lower frequencies

f_2=reading on the exciter dial when approaching the same frequency from the side of higher frequencies

The repetitive frequency setting error characterizes the play in the system of transmission from the exciter frequency tuning control to its dial.

Frequency stability. The main factors causing variation in exciter frequency are the following:

internal heating: due to the fact that operation of the exciter causes gradual heating up of the valves, resistors, and other components. The temperature rise brings about a change in frequency. The time it takes the temperature to stabilize depends on the design of the exciter and may lie between several minutes and two hours;

variation of ambient temperature which brings about a change in the heat exchange conditions. For the heat balance to be restored, i.e., for the heat developed in the exciter to equal the amount of heat it radiates into the ambient medium, the temperature of the exciter must also change, that brings about a change in frequency;

variation of supply voltages, which causes a greater or lesser change in valve heater voltage, exciter anode and grid voltages, that causes a change in exciter circuit currents, and, consequently, a change in frequency;

replacement of valves: since the spread of parameters that exists in valves greatly affects their inter-electrode capacitances. Therefore, after valve replacement the calibration of the exciter may become significantly disturbed. In many cases during adjustment of the exciter such spare valves are set aside for the master oscillator, which little affect the calibration. Selection of valves and checking of the exciter after valve replacement is one of the important tasks of adjustment and checking. Of still greater impor-

tance is the checking of the effect of the valve replacement on the exciter frequency in those cases when no spare valves have been provided beforehand, and the master oscillator must operate normally using any valve of the given type whose parameters conform to the specifications.

Mechanical effects. Exciters designed for use in aircraft and rockets and also in mobile ground vehicles must operate normally under conditions of mechanical stress. For this the exciters are mounted on vibration stands and tested in an operating condition under mechanical loads. The main parameter checked in such cases is frequency stability.

When testing for frequency stability, use is made of the hookup shown in Fig. 82. All the measuring instruments

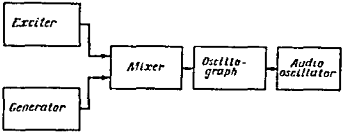


Fig. 82. Hookup for testing exciter for frequency stability

and the standard frequency generator should first be allowed to warm up, i.e., they should be in an operating condition for the time necessary for their parameters to stabilize. The warm-up time is specified in the instructions for each measuring instrument. The warm-up time required for the exciter is determined by testing the exciter for internal heating.

Tests for internal heating are carried out in the following way. The exciter frequency is measured immediately after switching on, then in every 2-3 minutes at first, and subsequently seldomer. On the basis of the measurement results a curve of the frequency drift is plotted (Fig. 83) which shows how the exciter frequency f changes with time t due to internal heating. From this curve it is easy to

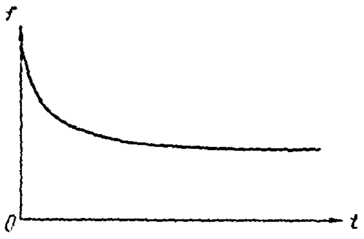


Fig. 83. Frequency drift curve

determine the time required for stabilizing the thermal conditions of the exciter and, consequently, for its frequency.

Let us consider the operating principle of the hookup for testing frequency stability (see Fig. 82). Prior to the action of the destabilizing factor on the exciter under test, but after it has warmed up, a frequency is set on the standard generator, which differs from the exciter frequency by several hundred hertzes. At the mixer output there develops the beat or difference frequency

$$F = f_s - f_e$$

where f_s =frequency of the standard generator
f_e =frequency of the exciter under test
F=beat frequency

The beat frequency voltage is applied to one pair of deflection plates of the oscillograph, and voltage from audio oscillator AO, to the other pair of deflection plates. If beat frequency F and frequency of the audio oscillator F_{AO} are equal, a stationary ellipse will appear on the screen. For further testing it is important to know which of frequencies f_s or f_e is higher. To find the answer, the frequency of the standard generator should be increased a little, and then an ellipse should be obtained again by varying the frequency of the audio oscillator. If in this case the frequency of the audio oscillator has to be increased, then $f_s > f_e$, and if it has to be decreased, then $f_s < f_e$.

Now it is easy to determine the amount and the sense of the frequency drift caused by the destabilizing factor acting on the exciter. Let us suppose that $f_s > f_e$. If under the action of the destabilizing factor in order to obtain an ellipse we have to decrease the audio oscillator frequency ($F'' > F'$), this means that the frequency of the exciter under test has increased and that frequency drift Δf has a

positive sense (Fig. 84). The amount of the frequency change is determined by the difference in the audio oscillator frequencies before and after the action of the destabilizing factor $F'-F''$ on the condition that in both cases an ellipse was obtained on the oscillograph screen.

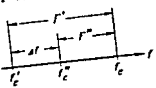


Fig. 84. Determining sense of frequency drift

Measuring the temperature coefficient of frequency (TCF). The effect of temperature on the exciter frequency is characterized by the *temperature coefficient of frequency*, by which is meant the relative change in exciter frequency with a change in the ambient temperature by 1°C

$$\mathrm{TCF} = \frac{\Delta f}{f \Delta t}$$

where Δt = change in temperature

Δf = change in frequency caused by a change in temperature by Δt°C

For measuring the TCF of the exciter, it is placed in a heat or cold chamber. The exciter should be allowed to warm up at normal temperature so as to exclude the effect of internal heating and then to measure its frequency f'_e. Next the temperature in the chamber should be increased by Δt°C and the exciter kept at this temperature for 2-[illegible] hours. After this frequency of the exciter f''_e is measured again. The temperature coefficient of frequency is det[illegible]mined by means of the equation

$$\mathrm{TCF} = \frac{f''_e - f'_e}{f'_e \Delta t}$$

Dependence of the exciter frequency on variation [illegible] voltages. The testing hookup is shown in Fig. 85. [illegible] from the preceding one in that the [illegible] via autotransformer ATr with [illegible] by voltmeter V.

After warm-up at the rated [illegible] frequency is measured. Then the [illegible]

within the limits indicated in the specifications, in both directions (for example, by +10 and −20 per cent). After setting the increased or decreased voltage, time should pass for the conditions to stabilize; this can be seen on the oscillograph screen (the speed of rotation of the image on

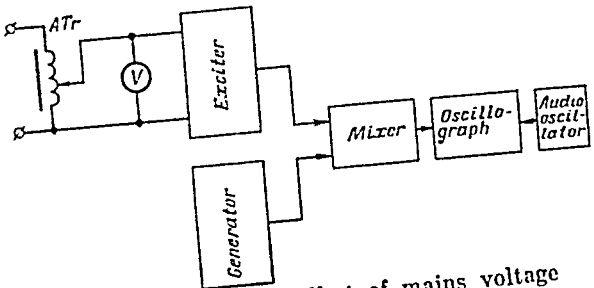


Fig. 85. Checking effect of mains voltage

it changes slowly). After conditions have stabilized, the frequency should be measured again and the sense and amount of frequency departure determined by the method used above.

Effect of valve replacement. The effect of valve replacement is determined with the aid of a preselected set of valves for the master oscillator, which differ in parameters (mutual conductance and interelectrode capacitances). After replacing a valve it is necessary to wait for a certain time for conditions to stabilize. After this the frequency is measured and compared to that set on the dial.

The effect of the replacement of valves is checked at several points of the band and necessarily at the extreme frequencies. Due to variations in interelectrode capacitances, the frequency range may shift towards either highe or lower frequencies, and the frequency coverage of th variable capacitor may change.

Effect of variation in load. The effect of the load o the oscillator frequency is checked by de-tuning the ta circuit of the stage that loads the exciter. Having measu ed the exciter frequency with the tank circuit of the fol wing stage, tuned, de-tune the tank circuit so as to obta

maximum change in the exciter frequency. The difference in the exciter frequency with the following stage tuned and de-tuned characterizes the frequency departure due to the effect of variation in the load.

Effect of mechanical loads. Checking the effect of mechanical loads on the exciter frequency is especially important in the case of equipment intended for operation under conditions of mechanical overloads (motor vehicles, aircraft, ships, rockets, railways, etc.).

Stationary equipment is only tested for vibration strength, i.e., the stability of the exciter calibration is checked after subjecting it to mechanical loads.

In testing for vibration strength the exciter is mounted on a vibration stand and subjected to mechanical loads with the exciter power switched off. In this case all the tuning controls should be detented. After testing, the calibration of the exciter frequency dial is checked.

In testing for vibration stability, power is applied to the exciter mounted on the vibration stand. After a warm-up to exclude the effect of internal heating, its frequency is measured. During vibration a check is made for the absence of signal irregularity and of the level of parasitic frequency modulation with the aid of a deviation frequency meter. After checking the effect of mechanical loads, the calibration of the exciter frequency scale is verified.

Determining the pull-in band of the automatic frequency control. One of the effective ways of increasing the reliability of radio communication is the use of automatic frequency control systems. The operation of an AFC system is characterized by the pull-in band and the hold-in band. By pull-in band is meant that band of frequencies within which synchronization of the exciter is ensured by the signal of the correspondent, which approaches the exciter frequency from outside the band or, on the contrary, when the exciter, operating in the search mode, varies its frequency, approaching the frequency of the synchronizing voltage.

Let us suppose that the exciter is synchronized by the correspondent's signal, but under the action of destabilizing factors its tuning changes. There is a certain band of frequencies, the hold-in band, within which changes ›e

tuning of the exciter do not violate synchronization. The hold-in band is broader than the pull-in band. It is customary to measure only the pull-in band using the hookup shown in Fig. 86.

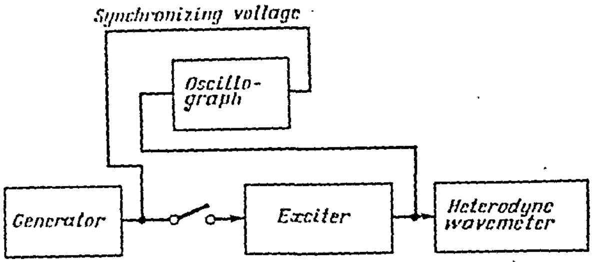


Fig. 86. Hookup for measuring pull-in band

The oscillograph is switched to the external synchronization mode. Its sweep is synchronized by voltage from the synchronizing generator. The output voltage of the exciter under test is applied to the vertical-deflection plates of the oscillograph. The input of the exciter is supplied with voltage from the synchronizing generator, the amplitude of which is set according to specifications. If the exciter frequency is synchronized with that of the synchronizing generator, a stable image of the sinusoidal voltage of the exciter will appear on the oscillograph screen. Otherwise the image will be blurred or instead of a sine wave there will be a luminous band on the screen.

To determine the pull-in band, it is first necessary to de-tune the exciter with respect to the frequency of the synchronizing generator so that there will be no synchronization. Then the frequency of the exciter or the generator should be changed so as to obtain a stable image of the exciter voltage. Having disconnected the synchronizing generator, measure the exciter frequency f_1 with the aid of a heterodyne wavemeter. Then, reconnecting the synchronizing generator vary its frequency in the same direction as when approaching frequency f_1, until synchronization stops. After this reverse the frequency until a stable image

of the exciter output voltage is obtained on the oscillograph screen. Disconnect the synchronizing generator and measure the exciter frequency f_2 which will be the other border frequency of the pull-in band. The difference between frequencies $f_1 - f_2$ gives the pull-in band.

Measuring Output Voltage and Level of Extraneous Waves

The sources of interference created by a transmitter may be the harmonics of the fundamental frequency and also parasitic oscillations. Both are classified as extraneous waves. According to current standards the power of extraneous waves at the output of transmitters operating within the frequency range from 10 kilohertzes to 60 megahertzes should be 40 decibels below the power of the radiation on the fundamental frequency.

Figure 87 shows a hookup for measuring the level of extraneous waves. The receiver is tuned to the fundamental

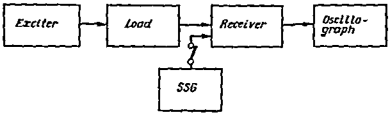


Fig. 87. Hookup for measuring level of extraneous waves

frequency of the exciter, after which its beat frequency oscillator is switched off and voltage from a standard signal generator is supplied to the receiver input. The SSG frequency is varied so as to obtain a beat note with the exciter frequency. The oscillograph screen will show an image characteristic of the beating of two radio frequency oscillations.

The amplitude of the SSG output voltage is selected so that the envelope of the obtained oscillations borders on the horizontal axis. In this case the image obtained

on the oscillograph screen is similar to that of amplitude-modulated oscillations at 100-per cent modulation (Fig. 88).

This means that the amplitude of the SSG voltage is equal to the amplitude of the fundamental oscillation of exciter V_1. Then the receiver is tuned to the frequency of

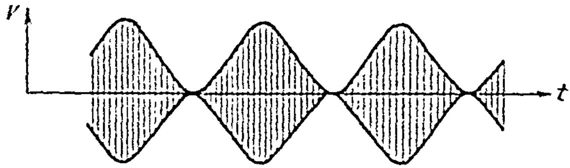


Fig. 88. Oscillogram of beating frequencies

extraneous waves and the same method is used for measuring the amplitude and frequency of the extraneous waves V_2.

The ratio of the SSG output voltages in the first and the second case $\left(\frac{V_2}{V_1}\right)$ characterizes the level of extraneous waves. To exclude the effect of interference, the level of extraneous waves is measured in a screened room.

7.5. MEASURING TRANSMITTER PARAMETERS

An adjusted transmitter is checked for conformity with its specifications. The procedure for conducting frequency tests does not differ from that discussed in the previous section, only in this case the circuit under test is not the exciter but the transmitter as a whole.

The frequency range of the transmitter may differ from that of the exciter, because the amplifier stages may operate in the frequency multiplication mode. The rest of the parameters that characterize frequency setting accuracy and stability are determined by the exciter.

The main parameters measured during testing of a transmitter are power and those parameters that characterize the quality of telephone and telegraph operation.

Measuring transmitter power. Previously it was stated that by the power of a transmitter is meant the power of

the radio frequency oscillations that it feeds into the antenna. In tests the antenna is usually replaced by a dummy antenna, i.e., by a resistor which will dissipate the same power that the transmitter feeds into the antenna. Transmitter power is measured in the telegraph mode with the key depressed and in the telephone mode in the absence of modulation (in the carrier-frequency mode).

Fig. 89*a* shows a hookup for measuring transmitter power on the basis of current I in the dummy antenna, and in

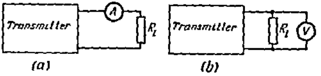


Fig. 89. Measuring transmitter power in dummy antenna
(*a*) on the basis of current; (*b*) on the basis of voltage

Fig. 89*b*, on the basis of voltage V across it. In the first case the transmitter power

$$P = I^2R_l$$

and in the second

$$P = \frac{V^2}{R_l}$$

where R_l is the resistance of the dummy antenna.

A hookup for measuring transmitter power by means of a photometric method is shown in Fig. 90*a*. In this case a suitable incandescent lamp L_1 is used as the dummy antenna. This lamp and a similar lamp L_2 are placed inside a photometer. The photometer makes it possible to compare the intensity of the two lamps and, consequently, the power that they are consuming. In respect of design the photometer is a light-proof case divided into two parts by a light-proof partition. In the front part of the case there is a frosted glass which is illuminated from inside by lamps L_1 and L_2.

on the oscillograph screen is similar to that of amplitude-modulated oscillations at 100-per cent modulation (Fig. 88).

This means that the amplitude of the SSG voltage is equal to the amplitude of the fundamental oscillation of exciter V_1. Then the receiver is tuned to the frequency of

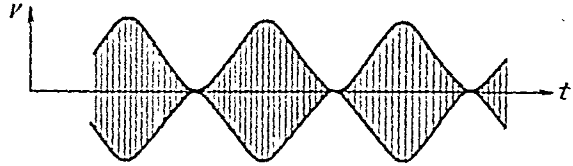


Fig. 88. Oscillogram of beating frequencies

extraneous waves and the same method is used for measuring the amplitude and frequency of the extraneous waves V_2.

The ratio of the SSG output voltages in the first and the second case $\left(\frac{V_2}{V_1}\right)$ characterizes the level of extraneous waves. To exclude the effect of interference, the level of extraneous waves is measured in a screened room.

7.5. MEASURING TRANSMITTER PARAMETERS

An adjusted transmitter is checked for conformity with its specifications. The procedure for conducting frequency tests does not differ from that discussed in the previous section, only in this case the circuit under test is not the exciter but the transmitter as a whole.

The frequency range of the transmitter may differ from that of the exciter, because the amplifier stages may operate in the frequency multiplication mode. The rest of the parameters that characterize frequency setting accuracy and stability are determined by the exciter.

The main parameters measured during testing of a transmitter are power and those parameters that characterize the quality of telephone and telegraph operation.

Measuring transmitter power. Previously it was stated that by the power of a transmitter is meant the power of

the radio frequency oscillations that it feeds into the antenna. In tests the antenna is usually replaced by a dummy antenna, i.e., by a resistor which will dissipate the same power that the transmitter feeds into the antenna. Transmitter power is measured in the telegraph mode with the key depressed and in the telephone mode in the absence of modulation (in the carrier-frequency mode).

Fig. 89*a* shows a hookup for measuring transmitter power on the basis of current I in the dummy antenna, and in

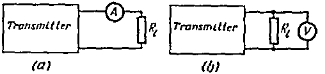


Fig. 89. Measuring transmitter power in dummy antenna
(a) on the basis of current; (b) on the basis of voltage

Fig. 89*b*, on the basis of voltage V across it. In the first case the transmitter power

$$P = I^2 R_l$$

and in the second

$$P = \frac{V^2}{R_l}$$

where R_l is the resistance of the dummy antenna.

A hookup for measuring transmitter power by means of a photometric method is shown in Fig. 90*a*. In this case a suitable incandescent lamp L_1 is used as the dummy antenna. This lamp and a similar lamp L_2 are placed inside a photometer. The photometer makes it possible to compare the intensity of the two lamps and, consequently, the power that they are consuming. In respect of design the photometer is a light-proof case divided into two parts by a light-proof partition. In the front part of the case there is a frosted glass which is illuminated from inside by lamps L_1 and L_2.

Lamp L_1 is supplied with radio frequency power from the transmitter, and the illumination of the left half of the frosted glass depends on its value. Lamp L_2 is supplied with a.c. mains voltage (frequency 50 hertzes) which can be adjusted with the aid of autotransformer *ATr*. The

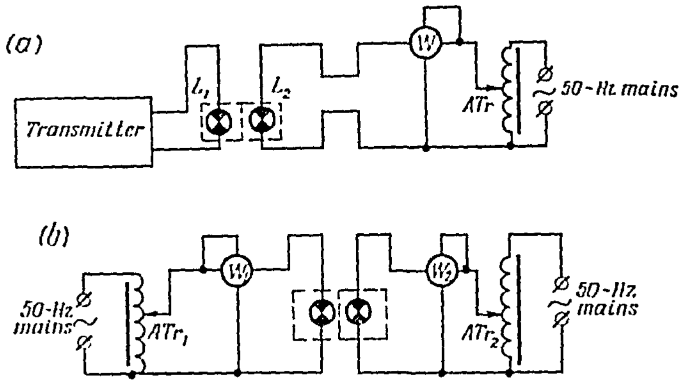


Fig. 90. Measuring transmitter power by photometric method
(a) measurement hookup; (b) calibrating circuit

power consumed from a.c. mains by lamp L_2 is measured by wattmeter W. By varying this power with the aid of the autotransformer, identical illumination of both halves of the frosted glass is obtained. The transmitter power is equal to the readings of the wattmeter, if both lamps are identical.

To make allowance for possible spread in the parameters of the lamps before measuring transmitter power, the hookup shown in Fig. 90*b* is assembled. Setting with the aid of autotransformer ATr_1 various powers according to wattmeter W_1, identical illumination of both halves of the frosted glass is obtained with the aid of autotransformer ATr_2 and the reading of wattmeter W_2 is noted. On the basis of the measurement results the curve $P_2=f(P_1)$ is plotted for identical illumination which is used in determining the transmitter power from the readings of wattmeter W in the hookup which is shown in Fig. 90*a*.

In high-power transmitters employing water-cooled valves, it is convenient to determine the transmitter power on the basis of the energy balance expressed by the equation

$$P_A = P_0 - P_a - P_c$$

where P_A = transmitter power
P_0 = power consumed by the output stage from the anode supply source
P_a = anode dissipation of the output stage valve
P_c = power loss in the intermediate tank circuit

The power consumption is determined from the readings of the ammeter measuring the d.c. component of anode current I_0 and of the voltmeter measuring the d.c. voltage at anode V_a

$$P_0 = V_a I_0$$

The anode dissipation is determined by the readings of an instrument which measures the difference in temperature of the water flowing to the anode and that flowing from it. At a constant rate of flow of the water in the anode cooling system, the difference in the temperature of the water flowing to the anode (cooled) and that flowing away (heated by the valve anode) is directly proportional to the anode dissipation, that makes it possible to calibrate the temperature difference meter directly in units of the dissipated power.

To determine the power dissipated in the intermediate tank circuit P_c, it is necessary to note the current in the intermediate circuit during normal operation of the transmitter and then to reduce the anode voltage and disconnect the antenna. With the antenna disconnected the power of the anode supply source is expended only on the anode and in the intermediate circuit. If now an anode voltage V'_a is set at which the current flowing in the intermediate circuit will be the same as that with the antenna connected, then the power dissipated in this circuit P_c will be the same as during normal operation of the transmitter. It can be easily determined proceeding from the energy balance for the case when the antenna is disconnected.

$$P'_0 = P'_a + P_c$$

whence

$$P_c = P_0' - P_a'$$

When all the terms of an energy balance equation at normal operation of the transmitter are known, it is possible to determine that power which the transmitter feeds into the antenna

$$P_A = P_0 - P_a - P_c$$

In the range of super-high frequencies the calorimetric method can be used for direct measurement of the power dissipated in the dummy antenna, i.e., the power of the transmitter. In this case the dummy antenna is in the form of a reservoir of water which absorbs all the power of the transmitter. The water in the reservoir is constantly renewed at a definite rate, which makes it possible to judge of the amount of super-high frequency power dissipated in the aquatic load by the difference in the temperature of the water flowing to the load and flowing from it.

Checking the quality of telephone operation in amplitude modulation. For amplitude modulation, use is made of audio frequency amplifiers with a microphone connected to their input. The sound oscillations strike the membrane of the microphone, varying the resistance of the microphone and the current in the circuit. A microphone transformer singles out the a.c. component of the voltage, which varies in time in the same way as does the position of the microphone membrane under the action of the sound oscillations of the air with respect to the neutral position.

The output voltage of the audio frequency amplifier is applied to one or two electrodes of one of the transmitter stages and produces a variation in the amplitude of the radio frequency oscillations of the transmitter in step with the variations in the audio frequency voltage. This circuit is known as an amplitude modulator, and control of the amplitude of radio frequency oscillations is known as *amplitude modulation.*

Fig. 91*a* shows radio frequency oscillations modulated in amplitude by a pure sinusoidal voltage. The amplitude of envelope V_Ω is the greater the higher the audio frequ-

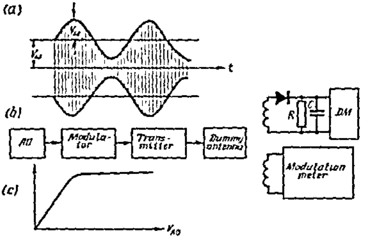


Fig. 91. Measuring amplitude modulation characteristics of AM transmitter

(a) amplitude-modulated RF voltage; (b) measurement hookup; (c) amplitude modulation characteristic

ency voltage, i.e., the louder the sound acting on the microphone membrane. The ratio of the envelope amplitude to carrier amplitude V_ω is called the *modulation factor*

$$m = \frac{V_\Omega}{V_\omega}$$

The relationship between the modulation factor and the voltage at the modulator input is called the *modulation characteristic* of the transmitter. This characteristic is measured with the aid of a modulation meter employing the hookup shown in Fig. 91*b*. The modulation meter is inductively coupled to the antenna or the dummy antenna. Voltage from an audio oscillator is supplied to the modulator input. The modulation factor is measured by varying the amplitude of this voltage, while maintaining a constant modulation frequency. The measurement results are used to plot a modulation curve (Fig. 91*c*).

From this curve it can be seen that at high audio frequency voltages there is no direct proportionality between

the modulating voltage and the modulation factor. This produces nonlinear distortion of the transmitted signal. Specifications state the maximum depth of modulation at which the nonlinear distortion does not exceed the permissible value.

For measuring nonlinear distortion, use can be made of a distortion meter coupled by a loop to the transmitter antenna and a linear detector. With the aid of an *RC* filter, the envelope of the modulated oscillations develops at the output of the linear detector. The resultant audio voltage is supplied to the distortion meter. If the distortion factor does not exceed the permissible value, the transmitter conforms to the specifications in this parameter characterizing the quality of telephone operation. Otherwise, it is necessary to determine whether the nonlinear distortion occurs in the modulator or in the radio frequency channel of the transmitter, for which the amplitude response of the modulator is measured. This characteristic is measured in the same way as was done in the case of AF amplifiers.

The quality of telephone operation also depends on the level of noise produced by parasitic modulation of the radio frequency oscillations. The causes of noise may be pulsation of the supply source voltages, parasitic oscillations, sparking, flashovers, poor screening of the input circuits of the modulator.

For measuring noise level use can be made of the voltmeter of a distortion meter coupled to the transmitter as shown in Fig. 91*b*. Having set the output voltage of the audio oscillator to the voltage which produces the maximum modulation factor given in the specifications, measure the voltage at the output of the linear detector with the voltmeter of the distortion meter. After this the modulator input should be short-circuited and the output voltage of the linear detector measured again. The relationship of these voltages, expressed in percentage, characterizes the noise level

$$M_n = \frac{V_0}{V_m}\ 100\%$$

where V_0 = voltage at the linear detector output with the modulator input short-circuited

V_m = voltage at the linear detector output at the given modulation factor

Checking the quality of telephone operation in frequency modulation. In frequency modulation the modulator does not control the amplitude but the frequency of the radio frequency oscillations of the transmitter. As in amplitude modulation, an increase in the volume of sound brings about an increase in the amplitude of the modulator output voltage which in its turn brings about an increase in frequency deviation. The relationship between the frequency deviation and the amplitude of the modulating voltage is known as the modulation characteristic of a frequency-modulated transmitter (Fig. 92*a*).

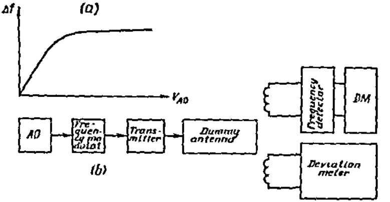


Fig. 92. Measuring amplitude modulation characteristics of FM transmitter

(*a*) amplitude modulation characteristic; (*b*) measurement hookup

The hookup for measuring this characteristic (Fig. 92*b*) differs from that shown in Fig. 91*b* only in that instead of a modulation factor meter, a frequency deviation meter is used, and instead of a linear detector, frequency detector (discriminator). All other considerations regarding the evaluation of the quality of telephone operation by means of the amplitude modulation characteristic and measurement of nonlinear distortion, as well as the evaluation of the noise level pertain just as much to frequency-modu-

ated transmitters as they do to amplitude-modulated transmitters.

Checking the quality of telegraph operation. The telegraph signals radiated by the transmitter antenna take the shape of radio frequency pulses. After detection of the radio pulses, it is possible to obtain their envelope, or video pulses, and to observe them on an oscillograph. If a series

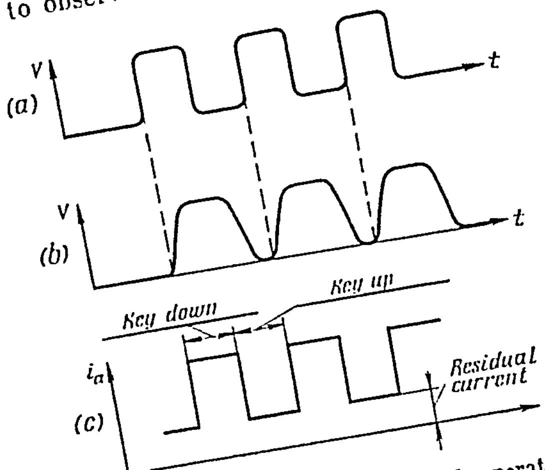


Fig. 93. Checking quality of telegraph operation

(a) series of dots with no distortion; (b) series of dots at high-speed telegraph operation; (c) series of dots with incomplete cutting off of transmitter

of dots is transmitted and there is no distortion, the pi
ture on the oscillograph screen will be like that shown
Fig. 93*a* (a series of video pulses of the same duration w
pauses equal to the duration of the pulses). The pau
correspond to the time when the key is released.

With an increase in the speed of the telegraph trans
sion, the duration of the pulses decreases and the lea
and trailing edges become drawn out (Fig. 93*b*). Sim
neously the duration of the pauses decreases. These fa
can bring about a merging of the pulses, i.e., distorti
the telegraph signal. One can judge of the presence o
distortion by the magnitude of the d.c. component

transmitter anode current. In the absence of distortion, the d.c. component of the anode current remains constant with variation in the speed of transmission of the dots. Distortion brings about an increase in current with an increase in the speed of transmission of the dots.

Another type of distortion in telegraph transmission is incomplete cutting off of the transmitter during pauses (Fig. 93c). In the case of incorrect operating conditions in the output stage, anode current i_a does not stop when the key is released and, consequently, the current in the antenna only decreases. Such distortion can be detected by listening to telegraph operation on a receiver. The residual current in the antenna produces a continuous background sound in the receiver, which accompanies the reception of telegraph signals and disappears only when the transmitter is switched off.

Review Questions

1. What are the functions of a transmitter CIS system? How can it be checked?
2. How are master oscillators adjusted? How can tuning of an exciter be controlled by a single knob?
3. How are the intermediate and output stages of a transmitter adjusted?
4. Which factors cause shifts in transmitter frequency? How is frequency stability checked?
5. Which parameters and characteristics determine the quality of telephone operation of a transmitter? How are they measured?
6. How can the power of a transmitter be measured by the photometric method, by the energy balance method?
7. How can the quality of telegraph operation of a transmitter be checked?

CHAPTER VIII

Adjusting and Testing Pulse Transmitters

8.1. PARAMETERS

By *pulse transmitters* are meant such transmitters that supply the antenna with short radio frequency pulses separated by comparatively long pauses. In other words, the duration of RF pulse τ is many times less than recurrence period T (Fig. 94*a*).

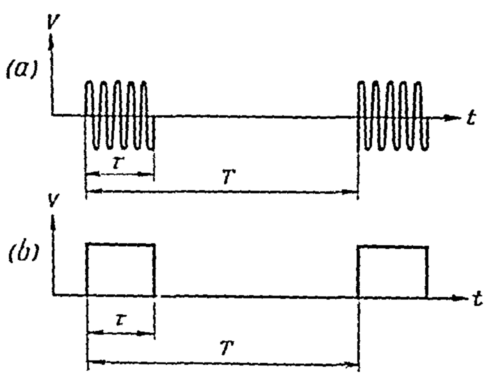


Fig. 94. Types of pulse signals
(*a*) RF pulses; (*b*) video pulses

The radio pulses radiated by the antenna of the transmitter are picked up by the receiver where they are amplified, detected, and converted into video pulses (Fig. 94*b*).

Among the frequency parameters of a pulse transmitter are carrier frequency f_0 and pulse recurrence frequency

$F_r = \frac{1}{T}$. Stable reception of the transmitter signals depends, among other things, on the stability of the transmitter carrier frequency.

Among the important parameters of a pulse transmitter are the duration of radio pulse τ and the power which is supplied into the antenna (or dummy antenna) during time τ. The ratio of the recurrence period to the pulse duration is known as the *pulsing ratio*

$$Q = \frac{T}{\tau}$$

The transmitter radiates radio frequency energy during a pulse and does not radiate energy during a pause or space. The ratio of energy W radiated during a pulse to the duration of the pulse is known as the *pulse power*

$$P_p = \frac{W}{\tau}$$

The average power of the transmitter

$$P_{av} = \frac{W}{T}$$

The pulse power and the average power are related by the equality

$$P_p \tau = P_{av} T$$

whence

$$P_p = P_{av} \frac{T}{\tau}$$

From the resultant equality it can be seen that with a low average transmitter power it is possible to obtain a very high pulse power if the recurrence period $T \gg \tau$.

Pulse transmitters are often used for determining the co-ordinates of various objects, and in these cases the measuring accuracy depends on the shape of the radio pulse. The closer the pulse shape to a square, the less the measuring errors, therefore radio pulses often should meet high requirements in respect of shape.

The transmitter is connected to the transmitting antenna by means of an energy transmission line or feeder.

The antenna-feeder array may also include various matching and tuning elements. In the SHF range it is very important to ensure good matching of all the elements in the system, i.e., the elements should not reflect SHF energy.

The antenna should possess resistance R_e equal to the wave impedance of feeder ρ_f, so that all the energy passing through the feeder is fully absorbed by the antenna. In case $R_e \neq \rho_f$, part of the energy will be reflected from the junction of the antenna and feeder and will return back to the generator. But to ensure matching of the antenna and the feeder is not in itself sufficient. Such conditions must also be created that the SHF generator itself will develop the maximum power. This will be obtained in the case when the input impedance of the feeder is equal to the internal resistance of the generator, i.e., $r_i = \rho_f$.

Thus, the best matching is obtained when the resistance of the antenna or dummy antenna is equal to the wave impedance of the feeder, which, in its turn, is equal to the internal resistance of the generator. If the internal resistance of the generator possesses a reactive component, the conditions for obtaining the maximum power from the generator acquire the following form

$$Z_i = Z_{in.f}$$

where Z_i, $Z_{in.f}$ = internal impedance of the generator and the input impedance of the feeder

x_i and $x_{in.f}$ = reactive components of these impedances

8.2. ADJUSTING AND CHECKING PARAMETERS

A pulse transmitter consists of an oscillator, a modulator, supply sources, and auxiliary circuits. Magnetrons and powerful klystrons are used as oscillators of radio pulses.

Let us consider the operation of a magnetron oscillator. Pulse operation of the magnetron is ensured by the modulator which accumulates energy during pauses and releases it during the brief pulses.

Figure 95 shows the block diagram of a pulse transmitter. The high-voltage rectifier is loaded by a reservoir. The reservoir consists of capacitors which charge during pauses.

When the discharge tube opens the magnetron, the reservoir capacitors feed the energy they have accumulated to the magnetron. The magnetron converts the energy of the reservoir pulse into radio frequency energy.

The submodulator forms video pulses which control the operation of the discharge tube. It determines the recurrence frequency of the magnetron pulses.

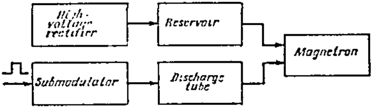


Fig. 95. Block diagram of pulse transmitter

The procedure for preliminary checking of a pulse transmitter is the following:

check the wiring, the insulation resistance, and the CIS system;

check the rectifiers;

check the d.c. operating conditions of the valves.

The procedure for preliminary checking of a pulse transmitter does not differ on the whole from that considered in Sec. 7.2.

Checking the submodulator. Pulses developed at the output of the submodulator must meet certain requirements in respect of their amplitude, duration, shape, and recurrence frequency.

For checking the pulse recurrence frequency use can be made of the hookup shown in Fig. 96*a*. The submodulator pulses are fed to the input of the vertical deflection amplifier of the oscillograph. Sweeping of the beam is provided by the voltage of an audio oscillator, which is applied to the horizontal deflection amplifier of the oscillograph. If the pulse recurrence frequency is equal to or a whole number of times less than the frequency of the audio oscillator, one pulse will be visible on the oscillograph screen (Fig. 96*b*).

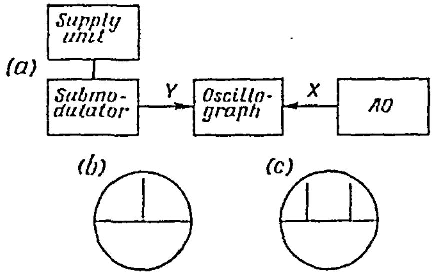


Fig. 96. Measuring pulse recurrence frequency
(a) measuring hookup; (b) and (c) oscillograms

Having obtained one pulse, the frequency of the audio oscillator should be decreased until two pulses are visible on the screen (Fig. 96c). In this case the frequency of the audio oscillator is half that of the pulse recurrence frequency.

$$F_{re} = 2F_{AO}$$

The duration and shape of the submodulator output pulse is checked with the aid of a pulse oscillograph. The pulse under investigation must be applied to the vertical deflection amplifier of the oscillograph (with a triggered sweep) and its image obtained on the screen (Fig. 97). With the duration calibrator of the oscillograph switched on, the pulse on the screen should be in the form of an intermittent trace. The time interval between neighbouring dashes (the marker value) is indicated on the scale of the duration calibrator switch.

The pulse duration is determined on a given level which is expressed in tenths of amplitude V_m. For example, when measuring the pulse duration at the $0.1V_m$ level, point A should be regarded as the beginning of the pulse and point B as its end. When measuring the pulse duration at the $0.5V_m$ level, the beginning and end of the pulse are limited by points C and F. The duration of the pulse leading and

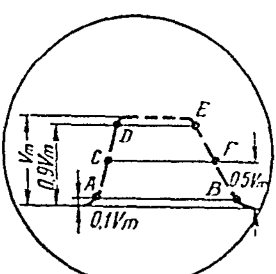


Fig. 97. Determination of pulse parameters

trailing edges is measured between the levels (0.1-0.9) V_m. Knowing the value of marker T_c, it is not difficult to determine all the parameters characterizing the shape of the pulse. From the example shown in Fig. 97 we obtain:

pulse duration at the $0.5V_m$ level $=6T_c$;
pulse duration at the $0.1V_m$ level $=8.5T_c$;
duration of leading edge $t_l=2T_c$, and duration of trailing edge $t_t=2.5T_c$.

The amplitude of the submodulator pulse is measured with the aid of the oscillograph amplitude calibrator or with a pulse voltmeter.

It is convenient to seek faults with the aid of an oscillograph, comparing the pulses at check points with the pulses at the same points of a submodulator known to be good. These pulses can be entered beforehand into the technological chart or into the adjustment instructions.

Checking the modulator. For observing the shape of the pulse fed from the modulator to the magnetron use is made of the circuit shown in Fig. 98.

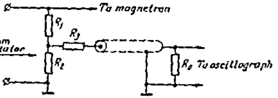


Fig. 98. Circuit for checking modulator

The voltage divider is necessary because the amplitude of the modulator pulse is great (of the order of units and tens of kilovolts) and, in addition, it is necessary to obtain matching so as to exclude distortion of the pulse shape. The voltage divider made up of resistors R_1 and R_2 must possess a high input resistance so as to exclude violation of the operating conditions of the modulator and the magnetron. Resistance of R_0 should be equal to the wave impedance of the cable, that will provide matching on the side of the cable output. For matching from the side of the cable input, resistor R_3 is determined from the equation:

$$R_3 = \rho - R_2$$

if $R_1 \gg R_2$.

The shape of the modulator pulse must meet quite stringent requirements. The leading and trailing edges of the pulse must not be too steep so as to avoid a number of undesirable phenomena in the operation of the magnetron (appearance of parasitic oscillations, sparking, etc.). At the same time they should be sufficiently steep, because they determine the steepness of the edges of the magnetron radio pulses which, in their turn, determine the precision and resolution of radar stations. The pulse top should be flat. Drooping of the top signifies that the magnetron anode voltage drops and, consequently, there is a change in its frequency, that can bring about violation of radio communication.

Checking the magnetron oscillator. The heater voltage of the magnetron is measured with the high voltage switched off. Non-observance of this rule is dangerous to life.

Before switching on the high voltage it is necessary to connect the antenna or a dummy antenna and to make sure that the cooling system is functioning properly. The high voltage should be increased gradually, and a new magnetron should be allowed to operate at reduced high voltage for at least ten minutes.

It is extremely important to obtain good matching of the magnetron with the resistance of the load into which it operates. In case of mismatching, the magnetron frequency changes and breakdowns are possible both in the magnetron itself and in the waveguide channel connecting the magnetron to the antenna.

The presence of radio frequency oscillations can be detected by one of the following signs:

the heating of the dummy antenna;

the glowing of a neon lamp or a voltage stabilizing tube brought up close to the antenna radiator;

the magnitude of the d.c. component of the magnetron anode current.

The working frequency of the magnetron is measured with a resonance wavemeter which is loosely coupled to the magnetron-antenna transmission channel with the aid of a directional coupler.

The directional coupler passes through nearly all the

energy of the radio frequency oscillations to the antenna without attenuation, directing only an insignificant part of it to the wavemeter.

The duration and shape of the pulses radiated by the *magnetron transmitter can be investigated with the aid* of a linear detector included in a waveguide channel coupled with a receiving antenna. The video pulses developed across the detector load present envelopes of the magnetron *radio pulses and can be investigated with the aid of an oscillograph.*

The circuit of another widely used method of investigating magnetron pulses is shown in Fig. 99. Small resistor R_1

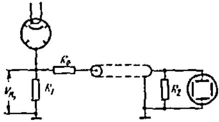


Fig. 99. Circuit for obtaining oscillogram of magnetron current pulse

of several ohms, which can have no practical effect on the operating conditions of the magnetron, is inserted in the magnetron anode circuit. Matching with the coaxial cable connecting resistor R_1 to the oscillograph is obtained in the following way: the cable is loaded by resistor $R_2=\rho$, where ρ is the wave impedance of the cable, while resistor $R_0=$ $=\rho-R_1$ is connected from the input side.

A voltage pulse is developed across resistor R_1, which has the same shape as the current pulse of the magnetron. *In its turn, the shape of the magnetron current pulse is close* to the envelope of the radio frequency pulse generated by the magnetron.

The obtained voltage pulse is applied to the vertical deflection plates of the oscillograph, while the horizontal deflection plates are supplied with a triggered sweep voltage.

The parameters of this pulse are investigated in the same way as the parameters of the modulator and submodulator pulses.

The average power of the radio frequency oscillations P_{av} can be measured with a calorimetric wattmeter which is connected instead of the transmitter antenna. The pulse power

$$P_p = \frac{P_{av}}{\tau F_{re}}$$

where τ = pulse duration

F_{re} = recurrence frequency of the radio pulses, which is equal to that of the modulator pulses

Checking the pulse transmitter with the aid of a spectrum analyzer. The RF pulse of a transmitter can be regarded as consisting of sinusoidal oscillations of various frequencies and amplitudes. The frequency dependence of these oscillations is called the *pulse spectrum* (Fig. 100).

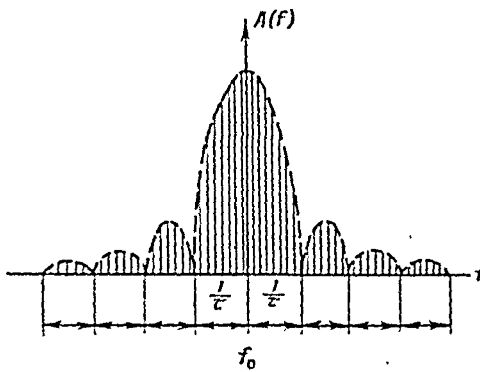


Fig. 100. Spectral diagram of RF pulse

The frequency is plotted along the horizontal axis, and sections proportional to the amplitudes of the spectrum components, along the vertical axis. If the sections plotted along the vertical axis are proportional to the squares of the amplitude, an energy spectrum is obtained, which

makes it possible to judge of the relationship of the energies making up the spectrum.

Carrier frequency of the transmitter f_c is located in the centre of the spectrum, and in normal operation it possesses the greatest amplitude. To both sides of the carrier the components of the pulse spectrum are located, which are removed from each other by a frequency interval equal to $\frac{1}{T_{r}}$, where T_{r} is the pulse recurrence period. The greater part of the pulse is located within the frequency band $2/\tau$ megahertzes (τ is the pulse duration in microseconds). In order to reproduce the transmitter pulse without undue distortion, the passband of the receiver should not be narrower than $2/\tau$; this pertains to the case when the transmitter pulse is undistorted. Any distortion that causes the transmitter pulse spectrum to broaden or causes displacement of its centre, will bring about deterioration or complete interruption of reception.

Checking of the spectrum pursues the following main aims:

measuring the spectrum width and comparing it to the specified;

determination of the amount of displacement of the spectrum centre with respect to the given value of the carrier frequency;

detection of instability of the spectrum for subsequent analysis and elimination of its causes.

By *spectrum width* is meant the frequency band between the closest minimums located to both sides of the spectrum centre. Of great importance is the symmetry and relative value of the side maximums. This value, as a rule, should not exceed 25-30 per cent of the main maximum.

Let us consider the operating principle of the spectrum analyzer, the block diagram of which is shown in Fig. 101. The pulse under investigation is fed to the spectrum analyzer receiver, to its mixer. The other input of the mixer is supplied with voltage from a wobbulator (frequency-modulated oscillator). Currents of all the spectrum components flow in the anode circuit of the mixer, but none of them passes through to the oscillograph because of the narrow-band intermediate frequency amplifier. Nor does the IF amplifier

pass the voltage of the wobbulator. Only when the difference in frequency between the wobbulator and one of the pulse spectrum components becomes equal or close to the intermediate frequency of the narrow-band IF amplifier will current of this difference frequency appear at the output of the narrow-band IF amplifier.

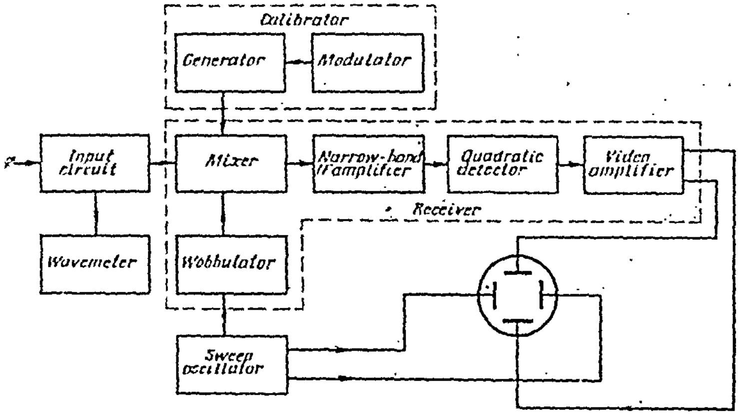


Fig. 101. Block diagram of spectrum analyzer

Voltage at the output of the quadratic detector, proportional to the energy of the given spectrum component, is amplified by the video amplifier and produces a vertical burst. After a certain time interval, the frequency of the wobbulator approaches the frequency of the next spectrum component. The difference between these frequencies falls within the passband of the IF amplifier, and across the vertical deflection plates of the tube a voltage proportional to the energy of the given spectrum component appears.

In the time interval under consideration the sweep voltage changes, therefore the vertical burst of the second component becomes displaced to the right of the first one. In a similar way vertical bursts are produced by all the other components of the spectrum. The relationship of the height of the vertical lines allows us to judge of the relative energies of the spectrum components.

For measuring the width of the spectrum, the analyzer incorporates a frequency calibrator consisting of a generator and a modulator.

The generator frequency is set equal to the middle frequency of the spectrum. The modulator supplies the generator with a series of harmonics of a standard frequency, for example, a frequency of 1 megahertz. As a result of the mixing of calibrator oscillations and those of the wobbulator, bursts spaced a definite frequency interval apart (in our case 1 megahertz) appear on the screen. These intervals form a frequency scale with the aid of which it is possible to determine the width of the spectrum. To distinguish the bursts caused by the calibrator, the level of the calibrator signal can be adjusted so that these bursts exceed in amplitude the bursts caused by the spectrum components (Fig. 102).

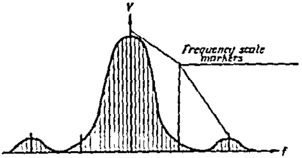


Fig. 102. Oscillogram of RF pulse spectrum with frequency scale markers

In addition to measuring the spectrum width and evaluating the symmetry and the relationship of the energies of the main and side lobes, with the aid of a spectrum analyzer, on the basis of spectrum distortion it is possible to detect a number of faults.

Thus, if some lines are missing from the spectrum (the spectrum is intermittent), as shown in Fig. 103*a*, this indicates skipping of transmitter pulses due to a fault of the modulator. The absence of clearly defined minimums in the spectrum (Fig. 103*b*) signifies that the radio pulses possess a badly distorted shape. The presence of two big maximums

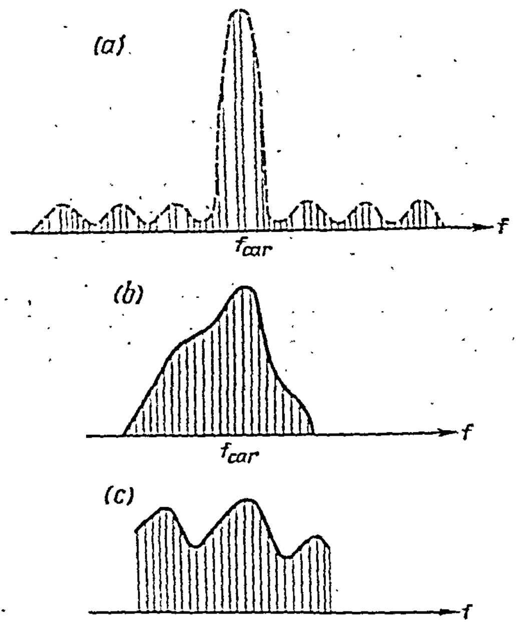


Fig. 103. Distortion of spectrum

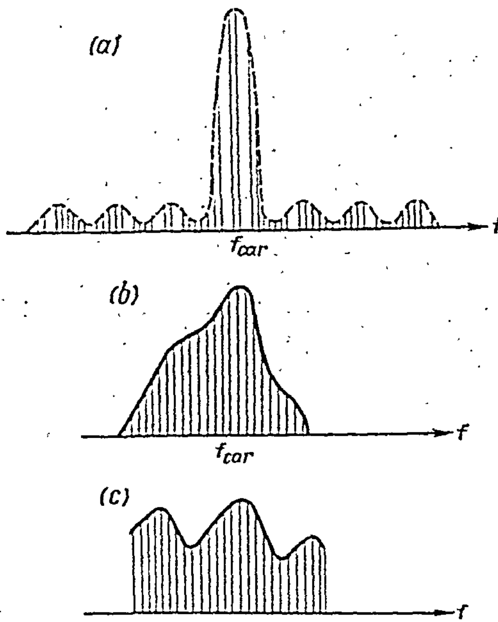
(a) some lines missing from spectrum; (b) clearly defined minimums absent; (c) several big maximums present

in the spectrum (Fig. 103c) may be the result of poor matching in the channel connecting the transmitter and the antenna. A frequency shift in the maximum indicates violated stability of the magnetron frequency, what is more, the greater this shift and the faster the maximum moves along the frequency axis of the spectrum analyzer, the less stable the operation of the magnetron.

Review Questions

1. Describe the functions and parameters of a pulse modulator. How can these parameters be measured?
2. What are the rules for switching on a magnetron oscillator? How can an oscillogram of the current pulse of a magnetron be obtained?

3. How to measure the pulse power of a magnetron oscillator?
4. Explain the operating principle of a spectrum analyzer on the basis of the block diagram shown in Fig. 102.
5. How are the parameters of RF pulses measured with the aid of a spectrum analyzer?
6. Which faults of a pulse transmitter can produce the spectrum distortions shown in Fig. 103?



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Review Questions

1. Describe the functions and parameters of a pulse modulator. How can these parameters be measured?
2. What are the rules for switching on a magnetron oscillator? How can an oscillogram of the current pulse of a magnetron be obtained?

3. *How to measure the pulse power of a magnetron oscillator?*
4. Explain the operating principle of a spectrum analyzer on the basis of the block diagram shown in Fig. 102.
5. How are the parameters of RF pulses measured with the aid of a *spectrum analyzer?*
6. Which faults of a pulse transmitter can produce the spectrum distortions shown in Fig. 103?

CHAPTER IX

Adjusting and Testing Broadcast and Communication Receivers

9.1. PARAMETERS AND CHARACTERISTICS

The purpose of radio receiving circuits is to catch the energy of electromagnetic waves from surrounding space and to single out the useful information they contain.

The simplest radio receiver consists of an antenna, a detector, and earphones. The electromagnetic waves induce in the antenna the electromotive force of amplitude-modulated radio frequency oscillations. The detector singles out the audio frequency oscillations. The earphones reproduce the audio oscillations as sound.

Such a receiver is only able to receive powerful radio stations located not too far away.

In order to receive the signals of radio stations located at a great distance and also the signals of low-power transmitters, it is necessary to amplify the weak signals that are picked up by the receiver antenna. For this purpose RC amplifiers will not do, for they amplify not only the signals of the desirable radio station, but all the interference signals as well. The amplifier must amplify only a small band of frequencies which border on the carrier frequency of the transmitter whose signal is to be received.

As was already pointed out in Sec 6.1 this function can be performed by resonance radio frequency amplifiers which make use of the selective properties of tuned (oscillatory) circuits.

Radio receivers in which all the resonance amplifiers are tuned to the frequency of the received signal are known as *straight amplification receivers*. Such receivers possess a number of shortcomings, the most important of which are

a tendency towards self-excitation at high amplification and insufficient attenuation of interference caused by radio stations operating on neighbouring frequencies (insufficient adjacent-channel rejection).

Modern receivers usually employ the superheterodyne circuit. Its distinctive feature is the conversion of the frequency of any received signal into an intermediate frequency.

The block diagram of a *superheterodyne receiver* is shown in Fig. 104. The input circuit and the radio frequency am-

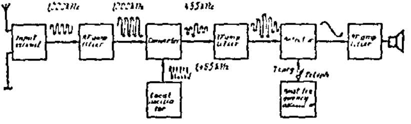

Fig. 104. Block diagram of superheterodyne receiver

plifier are tuned to the frequency of the received signal. In second-class receivers the RF amplifier is usually omitted. The tuning of the local oscillator is ganged with that of the input and RF circuit so that the frequency it generates is higher than the resonance frequency of these circuits by 465 kilohertzes. If the input and RF amplifier circuits are tuned to frequency of the received signal f_s, the frequency of the local oscillator is equal to $f_s + 465$ kHz. For example, if $f_s = 1{,}000$ kilohertzes, the local oscillator frequency $f_o = 1{,}465$ kilohertzes.

The anode circuit of the converter is tuned to the frequency of 465 kilohertzes, i.e., to the difference frequency between that of the signal and that of the local oscillator. Voltage of this frequency is supplied to the intermediate frequency amplifier, while the other components of the signal are filtered out both by the anode circuit of the converter and the tuned circuits of the IF amplifier.

The main amplification of the signal occurs on the relati-

vely low intermediate frequency, that considerably reduces the danger of self-excitation.

Another advantage of the superheterodyne receiver is that on a fixed intermediate frequency which does not depend on the frequency of the received signal it is possible to obtain a sufficiently broad passband with simultaneous high rejection of adjacent channels.

The intermediate frequency signal contains the same information as the radio frequency signal. If a telephone transmission is being received, the audio oscillations contained in the amplitude-modulated IF oscillations are singled out by the detector, amplified by the AF amplifier, and fed to the loudspeaker.

In order to obtain tonal reception of telegraph signals, communication radio receivers contain a beat frequency oscillator. The frequency of the beat frequency oscillator differs from the intermediate frequency by an audio frequency. The difference frequency between that of the BFO and the intermediate frequency is singled out by the detector and the tone of this frequency is heard in the headphones or loudspeaker in those intervals of time which correspond to the depressed position of the telegraph key. The receiver is switched from telegraph to telephone operation by means of the TELEG — TELEPH switch which switches the beat frequency oscillator on and off.

There are two forms of interference that an IF amplifier is incapable of filtering out: interference on a frequency close to the intermediate frequency of 465 kilohertzes and on the image frequency. If the frequency of the local oscillator is higher than that of the received signal by 465 kilohertzes, the image frequency interference will be by the same 465 kilohertzes higher than the local oscillator frequency, i.e., it will differ from the signal frequency by double the intermediate frequency.

It can be readily seen that the image frequency interference will form together with the frequency of the local oscillator the same difference frequency of 465 kilohertzes, which will be amplified in the same way by the IF amplifier as the frequency of the useful signal.

The task of attenuation of the image frequency interference falls on the input and RF tuned circuits.

To attenuate interference of frequencies close to the intermediate frequency, special filters (wave traps) are included in the antenna circuit of the receiver.

The main parameters characterizing the electrical properties of a radio receiver are the following: the range of received frequencies, sensitivity, selectivity, power output, and fidelity of reproduction.

In respect of the *range of received frequencies*, receivers are classified as long wave (from 150 to 415 kilohertzes), medium wave (from 520 to 1,600 kilohertzes), short wave (from 4 to 30 megahertzes), USW receivers (from 30 to 500 megahertzes), and super-high frequency receivers (above 2,000 megahertzes). Modern receivers have several wave bands.

The *sensitivity* of a radio receiver is its ability to receive weak signals. Quantitatively, it is expressed by the field intensity or the minimum e.m.f. induced in the antenna by the signal of the received station which will ensure a normal power at the receiver output.

By *selectivity* is meant the ability of the receiver to single out only the useful signal from the multitude of signals picked up by the antenna. It indicates how many more times the useful signal is amplified than the interference signals. The most probable intense interference is that caused by a station operating on an adjacent communication channel. By *adjacent channel* is meant a communication channel on the closest carrier frequency. Adjacent-channel selectivity is provided mainly by an IF amplifier.

The quality of reproduction of the information contained in the received signal depends on a number of parameters; two factors are the most significant.

The first is the frequency response, i.e., the band of audio frequencies that are passed without nonuniformity in gain exceeding a certain value. It should be noted that for high fidelity reception of music, a much broader passband is required than for the reception of speech; for the reception of telegraph signals, a narrower passband is required than for telephone communication. If the passband is inadequate, frequency distortion develops: part of the signal spectrum is attenuated and there occurs violation of the natural relationship between the amplitudes of the low-frequency and high-frequency components of the modulated voltage.

The second is the level of nonlinear distortion. Nonlinear distortion develops in the AF amplifier of the receiver and mainly in its output stage which operates at high signal amplitudes. The measurement of the distortion factor of AF amplifiers was dealt with in Sec. 6.2.

The fullest picture of the qualitative indices of a receiver and its individual parts is provided by its frequency and amplitude characteristics, the procedure for measuring which was dealt with in Chapter VI.

The block diagram of a receiver of frequency-modulated signals is shown in Fig. 105. It differs from the block diagram of an amplitude modulation receiver in that instead of an amplitude detector it employs a frequency detector which is often preceded by a limiter.

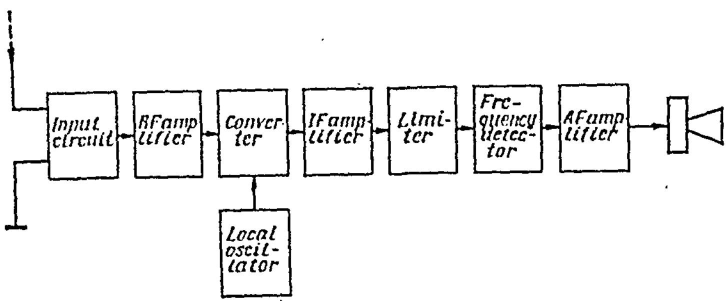

Fig. 105. Block diagram of frequency modulation receiver

The frequency detector converts the changes in frequency of the received signal into proportional voltage changes, reproducing the shape of the signal which controls the frequency modulator of the transmitter. A limiter is necessary in those cases when the frequency detector used is sensitive not only to variations in the frequency but also to variations in the amplitude of the signal. In the absence of a limiter, parasitic amplitude modulation worsens the quality of reproduction of the signal.

Receivers of frequency-modulated signals have a broader passband and are used for reception in the VHF band, including the reception of the sound signals accompanying television broadcasts.

If there is no reception on only one of the bands, the fault should be sought in the band switch circuits or in the RF and local oscillator tuned circuits. If there is no reception on any of the bands, stage-by-stage checking is carried out in the following order: AF amplifier, detector, IF amplifier, converter (mixer and local oscillator), RF amplifier, input circuit.

If loud crackling and noise is heard, it must first be ascertained whether the source of the interference is inside or outside the receiver. For this the antenna should be disconnected to ascertain whether the interference has disappeared. If the interference has disappeared, then most likely the source is outside the receiver.

In some cases interference develops inside the receiver only when a signal is applied to one of the stages, calling forth self-excitation. It usually manifests itself in the form of whistles, a steady tone, or intermittent oscillation. To find the faulty stage, the stages should be disconnected by turns beginning from the input, or their control grids should be short-circuited to the cathode, until the interference disappears.

The most likely causes of internal interference are faulty valves, faulty bypassing and decoupling circuits, and breaks in the grid circuits.

Let us consider some methods of checking the operation of receiver stages.

Checking the AF amplifier. A preliminary judgement about the operation of an AF amplifier can be made by the presence of noise at the receiver output or by the development of generation when artificial feedback is created between the output and input of the AF amplifier.

In the second case, to become convinced that the AF amplifier is in order, it is usually sufficient to touch the valve grid with a finger, having first connected headphones to the receiver output and put them on. In this case, due to the presence of significant inductances and capacitances in the amplifier circuits, self-excitation of the AF amplifier takes place on an audio frequency; it can be heard in the headphones. It is also possible to connect with a wire the valve grid lead to one of the secondary winding leads of the output transformer. Only both leads of the transformer

should be tried, since self-excitation will develop only when positive feedback is applied.

The appearance of a click when the grid lead is touched with a metal screw-driver also indicates that the AF amplifier is operating.

If a more reliable check of the normal operation of the AF amplifier must be made, then the voltage from an audio oscillator of about 0.25 volt should be applied to its input (to the jacks provided for a pickup, for example) to ascertain whether a pure tone of the normal volume is obtained.

Checking the detector and IF amplifier. An amplitude detector seldom fails, and therefore it is usually checked together with the last IF amplifier stage.

A preliminary judgement about the operation of the IF amplifier of an AM receiver can be made by touching the valve grid with the end of a metal screw-driver. This should produce a click because at the moment of contact the grid potential changes and there is a corresponding change in the anode current of the valve. The anode current jump produces damped oscillations in the IF amplifier tuned circuits; these oscillations are converted by the detector into a voltage pulse at the AF amplifier input. This pulse produces a brief click at the output.

The first stage of the IF amplifier (in the case of a two-stage IF amplifier) can be checked in the same way, what is more, the click should be louder because the damped oscillations which develop in the tuned circuit of the first stage are amplified by the second IF amplifier stage.

If more reliable checking of the operation of the IF amplifier is required, first the control grid of the last IF stage and then that of the preceding one should be supplied with an amplitude-modulated intermediate frequency voltage. It is desirable that the amplitude of this voltage and the depth of modulation be specified in the adjustment instructions, so that having aligned the IF amplifier circuits one can ascertain that there is a normal volume for the given parameters of the input signal.

When checking of the IF amplifier is combined with its alignment, then it is useful to connect a voltmeter to the receiver output and to align the IF tuned circuits, beginn-

ing with the last one, to maximum reading of the voltmeter, gradually reducing the output voltage of the SSG as alignment is approached.

Checking of the operation of a frequency detector and of the IF amplifier of a receiver of frequency-modulated signals differs in that the SSG must be frequency-modulated. If the frequency detector and the IF amplifier were not aligned beforehand, it is a good idea to combine checking with alignment, which will be discussed in the next section.

Checking the converter. The converter consists of a local oscillator and a mixer, which may employ one or two valves. It is first expedient to check the operation of the converter as a whole and only if it happens to be faulty to check the mixer and the local oscillator separately.

A preliminary judgement about the operation of the converter as a whole can be made in the following way: touch the signal grid of the converter with the antenna lead or a wire substituting for an antenna. At the moment of contact a click should be heard at the receiver output, which indicates that the anode circuit of the converter is in order. In addition, when the antenna is connected to the signal grid, the noise should increase, and when the receiver is tuned, signals of various radio stations should be heard.

To make sure that the local oscillator is in order, it is necessary to tune it in some station, and then to interrupt the oscillations of the local oscillator by short-circuiting the rotor and stator vanes of the oscillator section of the ganged variable capacitor. If reception of the signal stops, the local oscillator is in order and is taking part in the process of converting the signal frequency into the intermediate frequency.

It is more convenient and reliable to check the converter as a whole by means of an SSG with amplitude or frequency modulation, depending on the type of receiver. Having set a definite voltage and a given depth of modulation at the SSG output, it is necessary to apply this voltage to the signal grid of the converter and to tune the receiver to the SSG frequency. The presence of a signal of normal volume at the receiver output indicates that the converter is in order.

The mixer part of the converter can be checked in the same way as the IF amplifier is checked.

Operation of the local oscillator can be checked in the following ways:

checking the presence of RF voltage across the local oscillator tuned circuit with a valve voltmeter;

checking a change in the voltage across the resistors in the anode or screen-grid circuits when the oscillation of the local oscillator is interrupted;

checking the presence of a click when the local oscillator tuned circuit is shorted (when the local-oscillator oscillations are interrupted, the d.c. component of the mixer anode current increases, a current pulse is formed which acts on the following stages and a click is heard in the headphones).

Checking the radio frequency amplifier and input circuits. The RF amplifier is checked with the aid of an SSG in the same way as the converter as a whole. The input circuits are checked in a similar way. In the first case the SSG signal is applied to the grid of the RF amplifier valve, and in the second, to the antenna input of the receiver.

The operation of the input circuits, the RF amplifier, and the converter should be checked on all bands of the receiver. Fairly common faults in the band switching circuits may cause the receiver to operate normally on one band and not operate on another.

Checking the operation of the automatic gain control system. The automatic gain control (AGC) reduces gain when the amplitude of the signal at the receiver input increases. Usually a delayed AGC circuit is employed, the diagram of which is shown in Fig. 106; it also includes the last IF amplifier stage and the detector.

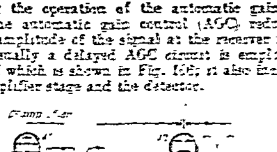

Fig. 106. Circuit of last IF amplifier stage, detector, and delayed AGC

Via a capacitor intermediate frequency voltage is applied from the last tuned circuit of the IF amplifier to the diode rectifier of the AGC which employs the right-hand half of diode $V2$. The anode of the rectifier is supplied via load resistor R_l with a negative voltage V_{del} of about 1.5-3 volts, which ensures delayed operation of the AGC. As long as the amplitude of the intermediate frequency voltage is less than the delay voltage, the AGC rectifier is cut off and exerts no effect on the operation of the receiver. During this time the grids of the controlled valves are under a certain bias voltage.

With an increase in the signal amplitude, the rectifier opens and current flows in its anode circuit, producing an additional bias at the grids of the controlled valves due to the voltage drop across resistor R_l. Resistor R_F and capacitor C_F form a filter which serves to prevent the a.c. component of the rectified voltage from reaching the grids of the controlled valves. With an increase in the signal amplitude there is a corresponding increase in the additional bias at the grids of the controlled amplifier valves, the operating conditions of which have been selected so that a change in bias causes a change in the mutual conductance of the valves, and consequently, in the amplification or gain of the stage. It should also be mentioned that with an increase in the signal amplitude there is a decrease in the d.c. component of the anode current of all the controlled valves.

The operation of the AGC system can be checked with the aid of a milliammeter or a voltmeter. The milliammeter is connected in series in the anode circuit of a controlled valve, the voltmeter is connected in parallel to any resistor included in the anode circuit, observing the rules for ensuring the least possible effect of the meter on the measured circuit.

The receiver should be tuned to the SSG frequency or to any sufficiently powerful radio station signal and the reading of the d.c. component of the anode current (or the d.c. voltage across the resistor) noted on the milliammeter. Then the receiver should be detuned or the SSG switched off. With the AGC functioning properly, the d.c. component of the anode current should increase noticeably. The operation

of the AGC can be checked in the same way in any controlled amplifier stage.

Normal operation of the AGC rectifier can be checked by short-circuiting filter capacitor C_F, having first tuned it in a sufficiently powerful signal. When the capacitor is short-circuited, the volume of the sound should increase.

9.3. ADJUSTMENT OF AMPLITUDE MODULATION RECEIVERS

The purpose of adjusting a receiver is to bring its parameters and characteristics to the values stated in the specifications or the State Standards. The methods of adjustment and checking of the parameters of amplifier circuits discussed in Sections 6.1-6.3 are fully applicable to corresponding circuits in receivers.

We shall now only deal with a few characteristic properties and with problems connected with the tracking of the radio frequency and local-oscillator tuned circuits.

If the adjustment of the receiver is made according to operational stages, the following procedure can be recommended:

1st work place—adjustment and checking of the AF amplifier;

2nd work place—adjustment and checking of the IF amplifier, the amplitude detector, and the intermediate frequency filter of the converter;

3rd work place—adjustment of the frequency coverage of the bands, tracking of radio frequency and local-oscillator tuned circuits;

4th work place—tuning of the intermediate frequency wave trap in the antenna circuit, adjustment of auxiliary circuits (AGC, beat frequency oscillator, tuning indicator), and general checking of the receiver.

These operations should be preceded by a check of the receiver operability. The number of identical work places may vary depending on the volume of production, the number of shifts, and the labouriousness of the operations. For example, the operations done at the 3rd and 4th work places are more time-consuming than those done at the 1st and

work places, and consequently, there should be more of 3rd and 4th work places.

If adjustment of the receiver is all done at one work place, is expedient to retain the same sequence of operations: hecking receiver operability, including checking the upply sources; adjustment of the AF amplifier, the ampliude detector, the IF amplifier and the mixer, the local oscillator, the RF amplifier and the input circuits, the IF wave trap in the antenna circuit, the auxiliary circuits; general checking of the receiver.

In large-batch and mass production there are no sources of radio and intermediate frequency voltages at the work places of the adjusters, that keeps the work places free of SSG and saves the time spent in re-tuning them. All the necessary radio and intermediate frequency voltages are supplied to the work places from a centralized standard signal generator.

Adjusting the audio frequency amplifier. The AF amplifier is adjusted in case its parameters and characteristics do not conform to specifications. The procedure for checking parameters and measuring characteristics was discussed in Sec. 6.2.

If the gain of the AF amplifier proves insufficient, the operating conditions of the valves should be checked first, or they should be replaced by valves known to be good. After this the operating conditions are checked against check charts. If the frequency response does not conform to specifications, it is necessary to check whether the circuit components conform to the rated value; this applies to those resistors and capacitors which affect the frequency response (the resistance of anode loads, the values of coupling capacitors, etc.).

When adjusting a two-stage amplifier, first the outpu stage must be checked and adjusted.

Adjusting the intermediate frequency amplifier and th intermediate frequency filter of the mixer. The aim pu sued in adjusting the IF amplifier is to obtain the requir sensitivity and selectivity, while ensuring the required p sband. The IF amplifier tuned circuits may be aligned one and the same intermediate frequency or de-tuned respect to one another to obtain a broader passband.

adcast and communication receivers employ IF amplifiers, the anode loads of which are two inductively coupled tuned circuits (Fig. 107). In most cases the coupling between the

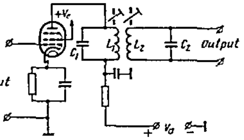

Fig. 107. IF amplifier with inductively coupled tuned circuits

tuned circuits is below the critical value. In this case the frequency response curve of the IF amplifier possesses a single hump. With the coupling above the critical value, the frequency response curve of the IF amplifier has two humps (Fig. 108).

Alignment of an IF amplifier is begun with its last stage, using as its load a detector and an AF amplifier that had been previously checked. The procedure for aligning with the aid of an SSG and an output meter or with a frequency response meter was dealt with in Sec. 6.1. Here we shall mention only a few specific features of alignment.

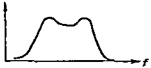

Fig. 108. Shape of IF amplifier response curve with coupling above critical value

If the given type of the receiver employs intermediate frequency filters with the coupling between the tuned circuits below the critical value, all the circuits are tuned to the intermediate frequency according to maximum reading of the output meter connected across the receiver output (speaker or headphones). When a frequency response meter is used, the amplifier is tuned according to the intermediate frequency marker on the frequency response curve observed on the screen of the meter cathode ray tube.

First the secondary circuit is tuned and then the primary one. The output voltage of the SSG (or the frequency response meter) should be selected so as to obtain convenient indication of the output voltage. Care should be taken that one of the stages does not become overloaded, for which the output voltage of the SSG is reduced, while aligning and crossing over to a preceding stage.

Overloading of a stage leads to the appearance of grid currents and to transition of the stage from the amplification to the limiting mode. Due to the shunting effect of the grid circuit upon the preceding stage, the output voltage begins to fall, even though the tuned circuit being aligned has not yet been tuned to the frequency of the SSG signal. In order to avoid spurious tuning, after the maximum output voltage of the receiver has been obtained, the output voltage of the SSG should be decreased somewhat. With normal alignment this should produce an increase in the output voltage of the receiver. In the case of spurious tuning, it will remain constant or decrease.

Another cause of spurious tuning can be that slug *1* of coil *2* which is being tuned has passed the position corresponding to maximum inductance (Fig. 109). Let us suppose that the capacitance of the IF tuned circuit capacitor is so low that the natural frequency of the tuned circuit is higher than the intermediate frequency even with the coil at maximum inductance. Then on passing through the maximum inductance position, the voltmeter will indicate maximum output voltage even though the circuit is off tune. Such spurious tuning is usually detected when measuring the sensitivity of the IF amplifier, which is found to be lower than the normal, or when measuring the passband which is found to be less than the normal. To ascertain whether there is spurious tuning a low-valued capacitor should be temporarily connected in parallel to the coil. If this causes the output voltage to increase, spurious tuning takes place.

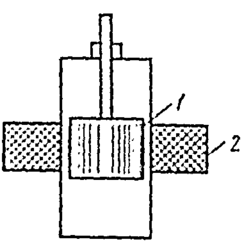

Fig. 109. Coil with variable inductance

When the primary circuit is tuned, de-tuning of the secondary circuit is possible due to the interaction of the two tuned circuits. Therefore, the two circuits should be tuned by turns several times, until adjustment of any of them will cause a decrease in the reading of the output meter.

When aligning IF amplifiers with single tuned circuits de-tuned with respect to one another, each circuit is tuned to its given frequency, after which it is shunted by a sufficiently high capacitance so that it does not affect the tuning of the subsequent stages of the IF amplifier.

The alignment of intermediate frequency filters with tight coupling between the coils, in which case a two-humped response curve is obtained (see Fig. 108), is carried out with the aid of a frequency response meter (alignment with the aid of an SSG is so time-consuming that it is not employed under conditions of serial production).

On obtaining the resonance response curve on the screen of the frequency response meter, it is necessary to position the centre of the trough on the intermediate frequency marker and the humps symmetrically with respect to the trough; the humps should be of the same height. If provision is made for adjusting the coupling between the coils, it should be selected so as to ensure the required passband at the highest selectivity. To facilitate alignment, a pattern of the required frequency response curve is fitted over the screen of the frequency response meter, and the adjuster brings in line with it the frequency response curve of the IF amplifier being aligned.

The intermediate frequency filter of the mixer is tuned in the same way as those of the IF amplifier. But in this case the oscillations of the local oscillator are temporarily interrupted.

It should be stressed once more that alignment should be carried out at the least possible output voltage of the SSG or the frequency response meter, so as to avoid overloading the stages and decreasing sharpness of tuning through the action of the AGC.

Adjusting the radio frequency stages. Alignment of the radio frequency stages includes tuning of the local oscillator, RF amplifier, and input circuits (Fig. 110).

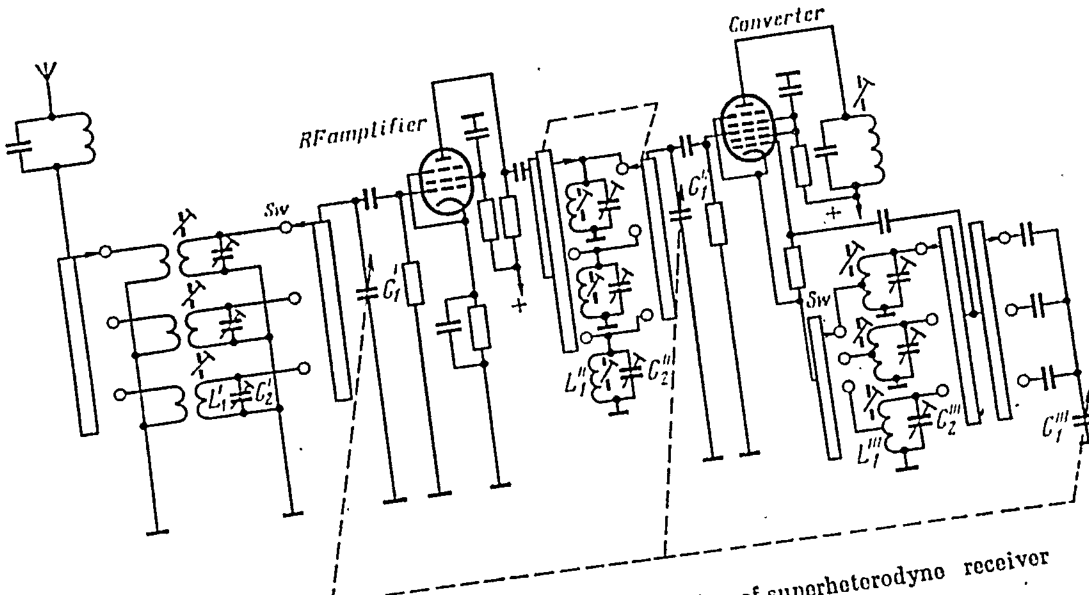

Fig. 110. Simplified circuit of radio frequency section of superheterodyne receiver

The tuning controls are the slugs of the coils and the trimming capacitors connected in parallel to the ganged variable capacitor. Turning the rotor of the ganged variable capacitor simultaneously changes the frequencies of the local oscillator, the RF amplifier, and the input circuits; the cursor of the receiver dial also shifts. The dial is inscribed with the frequencies of wavelengths to which the receiver should be tuned. The aim of alignment is to ensure coincidence of the actual tuning of the receiver with the readings of the dial.

Under laboratory conditions the tuned circuits of the local oscillator are aligned first so that the local oscillator frequency is higher than that set on the dial by the intermediate frequency of 465 kilohertzes. This operation is known as adjustment of band coverage.

Next the RF amplifier and input circuits are aligned. The aim of this operation is to obtain tracking of these tuned circuits with that of the local oscillator, so that tuning will coincide with the setting of the receiver dial, i.e., the RF amplifier and input circuits will be tuned to the frequency $f_s = f_{osc} - 465$ kHz, where f_{osc} is the frequency of the local oscillator.

The hookup for such alignment is shown in Fig. 111. Alignment is begun with the tuned circuits of the shortest waves, since the components of these circuits are often included in the circuits of the other bands. If the given rece-

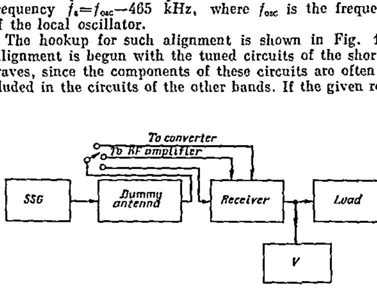

Fig. 111. Alignment of radio frequency stages of superheterodyne receiver

iver employs independent tuned circuits for the various bands, the order of alignment is not important.

When adjusting the frequency coverage of the bands, the SSG voltage is applied to the signal grid of the converter, and if there is a separate local oscillator, to the grid of the mixer. The receiver dial is set to the minimum frequency of the band and trimming capacitor C_2''', to a middle position. The SSG dial is set to the same frequency that was set on the receiver dial. Then by turning the slug of local oscillator coil L_1''', maximum reading of the output meter is obtained.

After this the SSG and receiver dials are set to the highest frequency of the band and the local-oscillator tuned circuit is adjusted with trimming capacitor C_2'''. Changing the capacitance of the trimmer slightly violates the tuning formerly obtained on the lowest frequency of the band. Therefore, tuning on the lowest frequency should be repeated. With this new readjustment, the inductance of the coil will change slightly and, consequently, the tuning on the highest frequency of the band will be violated, which also should be repeated.

Repeating these operations several times, it is possible to obtain tuning on both the highest and the lowest frequencies of the band. To ascertain that such is the case, the coil of the local oscillator, tuned to either the lowest or the highest frequency of the band, is approached by a stick made of insulating material, with a brass tip at one end and a magnetodielectrical tip at the other. When either end of the stick is brought close to the coil, the voltage at the receiver output should decrease.

On the short wave bands the limits of adjustment of the coil inductances may prove so extensive that there is a danger that the local-oscillator circuit may be tuned to the wrong frequency. Instead of the local oscillator frequency being higher than the signal frequency by the value of the intermediate frequency, it may by mistake be lower than the SSG (signal) frequency by the same amount.

To make sure that the tuning is correct, the SSG frequency should be increased by double the intermediate frequency, i.e., image frequency interference should be simulated. Since, when tuning the local oscillator, the SSG signal is

applied to the signal grid of the converter, the input and RF amplifier circuits cannot filter out the image frequency, and approximately the same voltage will appear at the receiver output as when tuning to the frequency of the main signal.

If the local-oscillator tuned circuit had been improperly tuned, increasing the signal frequency by double the intermediate frequency will produce no voltage at the receiver output.

And in fact, in this case the signal frequency will be higher than that of the local oscillator by triple the intermediate frequency, and the IF amplifier will be greatly off tune with respect to the difference frequency between the local oscillator and the signal.

Having completed tuning of the local oscillator circuits, tuning of the RF amplifier and input circuits is undertaken. The tuning of these circuits must track with that of the local oscillator, so that in any position of the ganged variable capacitor rotor the local oscillator frequency is higher than the tuning frequencies of the input and RF amplifier circuits by the intermediate frequency.

However, precise tracking can be obtained only at three points of the band. According to theory, the best tracking throughout the band is obtained in the case when exact tracking is obtained at the following points:

$$f_{mid} = \frac{f_{max} + f_{min}}{2}; \quad f_1 = f_{min} + 0.07\,(f_{max} - f_{min})$$

$$f_2 = f_{max} - 0.07\,(f_{max} - f_{min})$$

where f_{max}=maximum frequency of the band
f_{min}=minimum frequency of the band
f_{mid}=middle frequency of the band
f_1 and f_2=lowest and highest frequencies of exact tracking, respectively

For tuning the RF amplifier circuits, the output voltage of the SSG is applied to the control grid of the RF amplifier valve. The SSG and receiver dials are set to the lowest exact tracking frequency of the short-wave band (if there are common components in the RF tuned circuit for the various bands, then it is not all the same which band tuning is begun with).

The tuning procedure does not differ from that considered above. At the lowest tracking frequency, maximum receiver output voltage is obtained by varying inductance L_1'', and at the highest, by varying trimming capacitor C_2'', repeating these operations several times.

Having set one of the tracking frequencies on the SSG and receiver dial, the SSG should be readjusted slightly to maximum reading of the output meter, which will correspond to the local-oscillator frequency being higher than the signal frequency by exactly the intermediate frequency. After this, maximum reading of the output meter is obtained by adjusting the appropriate tuning components: the coil slug or the trimming capacitor.

When aligning RF amplifier circuits, the same mistakes are possible as when aligning IF amplifier circuits. In addition, spurious tuning is possible on the maximum tracking frequency, when:

the inductance of the RF coil is so high that the circuit does not tune even at minimum capacitance of the trimming capacitor. If the trimmer turns round and round, then passing through minimum capacitance will produce maximum reading of the output meter, that may by mistake be taken as tuning of the circuit to the signal frequency;

the inductance or capacitance of the tuned circuit is so low that tuning is not obtained even at maximum capacitance of the trimming capacitor. In this case passing of the trimmer through maximum will create the impression that the circuit has been tuned.

To make sure there is no spurious tuning, the coil inductance should be slightly increased and then slightly decreased by turning the coil slug. With correct tuning, the receiver output voltage will decrease in both cases.

The precision of tracking can be checked by setting the SSG to the middle frequency of the band f_{mid} and tuning the receiver to this frequency. With good tracking the reading of the receiver dial will correspond to frequency f_{mid} or will be close to it.

The input circuits are tuned in the same way as the RF amplifier circuits.

Under conditions of serial production the operations of tuning the oscillator, the RF amplifier, and the input cir-

cuits are combined. The adjuster's work place is supplied by cable from the central standard signal generator with voltages of all the frequencies necessary for tracking: three frequencies for each band. The amplitudes of these voltages can be adjusted at the work places.

Having set the lowest tracking frequency of the given band according to the receiver dial, the local oscillator, then the RF amplifier and input circuits are tuned, decreasing, as alignment is approached, the voltage of the central standard signal generator applied to the antenna jack of the receiver via a dummy antenna. After this the highest tracking frequency is set on the receiver dial and the tuning procedure is carried out in the indicated sequence.

As in the case of individual tuning, the indicated operations are repeated several times. The quality of the tracking is checked on the middle frequency of the band. The discrepancy between the reading of the receiver dial when tuning to the middle frequency of the given band and the true value of this frequency should not exceed a certain permissible value. The tolerance is usually specified directly on the technological scale according to which the receiver is tuned so as not to damage the receiver dial in the process of alignment.

Tuning the IF wave trap and adjusting the auxiliary circuits. To tune the intermediate frequency wave trap in the antenna circuit, voltage of the intermediate frequency from SSG is applied to the antenna jack of the receiver via a dummy antenna. The aligned receiver is tuned according to its dial to either the highest frequency of the long wave band or the lowest frequency of the medium wave band which are closest of all to the intermediate frequency of 465 kilohertzes. The wave trap is tuned to minimum reading of the output meter, increasing, as tuning is approached, the SSG voltage so that minimum reading is more clear cut.

Peculiarities of adjusting the transistor receivers. The circuit diagram of a transistor superheterodyne receiver is shown in Fig. 112. As most transistor receivers, this employs a built-in ferrite antenna *MA* which is made in the form of a ferrite rod carrying input circuit coils L_1 and L_2.

The frequency converter employs transistor T_1. The re-

ceived signal is applied to the base, the local oscillator signal, to the emitter of this transistor. The load of the converter is a three-tuned circuit lumped selectivity filter which ensures adequate adjacent channel rejection for the receiver.

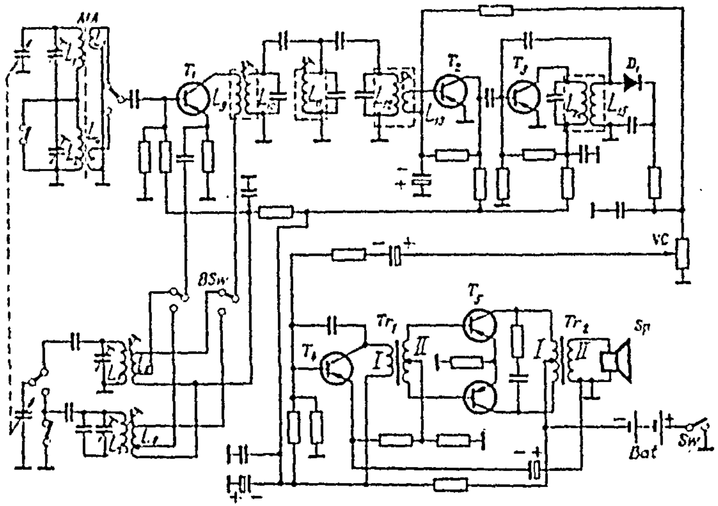

Fig 112. Circuit diagram of transistor superheterodyne receiver

From the filter output the signal is fed to a two-stage IF amplifier. Unlike valve receivers, the IF amplifiers of transistor receivers possess a broad passband and do not provide good rejection of adjacent channel signals, but do provide the basic amplification of the received signal. The first stage of the IF amplifier is aperiodic (it possesses no resonance properties). It employs transistor T_2 and has a low gain (of the order of 5-10). The second IF stage is a resonance amplifier with a high gain (employing transistor T_3). Transistors possess internal feedback between the collector and base circuits. At high amplification factor (gain), this can lead to unstable operation of the amplifier and even to its self-excitation. To neutralize the effect of the internal feedback, external feedback is

employed via a capacitor connected between coil L_{15} and the base of transistor T_3. Selection of the capacitance of the neutralization circuit capacitor is of great importance in the adjustment of the receiver.

In order to apply a calibration signal to the receiver input, a resistor of 80 ohms and a square standard loop, 380×380 mm, made of brass rod 6-8 mm in diameter, are connected in series to the output of the SSG. If the distance between the plane of the loop and the middle of the receiver antenna equals 1 metre, the field intensity at the place of reception, expressed in μV/m, will be equal to the product of the readings of the continuous and stepped attenuators of the SSG.

Transistor receivers are adjusted in the same order as valve receivers, i.e., stage by stage, working from the output to the input of the receiver.

A correctly assembled AF amplifier (employing transistors T_4, T_5, and T_6) requires no adjustment if the transistors and the rest of the circuit components are in order. Neither does the detector employing diode D_1 require any adjustment.

The intermediate frequency amplifier is aligned in the following order. The base of transistor T_3 is supplied, via a capacitor of 0.05 to 0.1 microfarad, with a signal of 465 kilohertzes at a modulation depth of 30 per cent from the SSG. The anode circuit of the tuned IF amplifier stage is tuned by turning the slug of coil L_{11}. After this the signal of the SSG is applied via the same capacitor to the base of transistor T_2 and the tuning is checked by varying the SSG frequency in the region of 465 kilohertzes. If maximum voltage at the receiver output is obtained at a considerable de-tuning exceeding ±4 kilohertzes, the value of the neutralization capacitor of the IF amplifier must be changed. If the tuning frequency proves to be higher than 465 kilohertzes, this means that the value of the capacitor is too high and that the stage is over-neutralized. On the contrary, if the tuning frequency is less than 465 kilohertzes, the capacitance of the capacitor should be increased, thus increasing the amount of external feedback in the tuned IF amplifier stage. After tuning the IF amplifier and checking the operation of the AGC, alignment of the lumped selecti-

vity filter is undertaken. For this the base of transistor T_1 is supplied, via a capacitor of 0.05-1 microfarad, with a signal of 465 kilohertzes at a modulation depth of 30 per cent.

Oscillation of the local oscillator is interrupted by connecting the emitter of transistor T_1 to the chassis via a capacitor of 0.03-0.05 microfarad. Then, turning the slugs of the lumped selectivity filter coils, maximum voltage at the receiver output is obtained.

For tuning the local-oscillator and input circuits, the signal from the SSG is applied to the receiver input with the aid of a standard loop connected to the output of the SSG, as described above. The procedure for tuning the local-oscillator circuits does not differ from that described for valve receivers. As for the input circuits, the only difference is that the inductance of the input coils is varied by shifting the movable parts of coils L_1 and L_2 along the ferrite rod.

General checking of the receiver includes measurement of the sensitivity and selectivity and a number of other parameters, as well as the measurement of characteristics. Whether the auxiliary circuits conform to the specifications is established during the process of general checking of the receiver.

9.4. ADJUSTMENT OF FREQUENCY MODULATION RECEIVERS

The tuning of the intermediate and radio frequency circuits of frequency modulation receivers does not differ from the procedure for amplitude modulation receivers, with the only difference that instead of an amplitude-modulated SSG, a frequency-modulated SSG is used. There is no difference in the general adjustment procedure and in the adjustment of the AF amplifier.

The main difference is in the methods of adjusting those stages which are specific for frequency modulation receivers: limiter and frequency detector (discriminator) or ratio detector which simultaneously fulfils the functions of suppressing the amplitude modulation of the signal and of converting the frequency-modulated intermediate-frequency

voltage into an audio frequency voltage. Adjustment of these circuits is begun after adjustment of the AF amplifier.

Adjustment of the limiter and discriminator. The circuit diagram of a limiter and a discriminator is shown in Fig. 113*a*. Limiter valve *V1* operates at reduced anode and

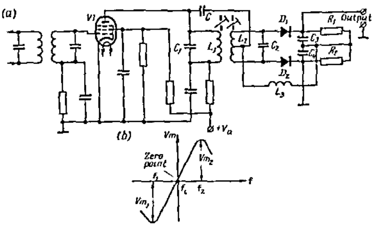

Fig. 113. Limiter and discriminator
(*a*) circuit; (*b*) discriminator frequency response

screen-grid voltages, that ensures limiting both due to the presence of grid currents and saturation limitation of the anode current at relatively low input signal amplitudes. As a result, variation of the input signal amplitude has practically no effect on the amplitude of the voltage across the anode tuned circuit. Whether the limiter operates normally is ascertained by checking the operating conditions of the valve.

The frequency response of a correctly tuned discriminator is shown in Fig. 113*b*. The zero point of the curve should coincide with intermediate frequency f_i. This means that if the instantaneous value of the frequency at the limiter input is equal to the intermediate frequency, the voltage at the discriminator output, and consequently, at the AF amplifier input should be equal to zero. When the frequency of the input signal departs to one side or

the other, the instantaneous value of the voltage at the discriminator output should change in magnitude and sense in proportion to this departure. The width of the frequency response f_2-f_1 and the difference between the amplitudes of the humps $V_{m1}-V_{m2}$ should be within specified limits.

These characteristics are obtained by tuning the discriminator tuned circuits. In laboratories and during repairs tuning is done with the aid of an SSG and a d.c. voltmeter. The unmodulated voltage of the SSG is applied to the input of the last IF amplifier stage or to the input of the limiter, while the voltmeter is connected to resistor R_2. The intermediate frequency is set on the SSG dial, and both tuned circuits of the discriminator are tuned to maximum reading of the voltmeter. After this the voltmeter is connected to the discriminator output and the second tuned circuit is tuned so as to obtain zero reading on the voltmeter.

A faster and more easily observable way of tuning the discriminator is with the aid of a frequency response meter. The output cable of the frequency response meter is connected to the input of the limiter or to one of the IF amplifier stages, and the input cable, to the output of the discriminator. The frequency response curve of the discriminator appears on the FRM screen.

The secondary circuit is tuned so that the zero point of the response curve coincides with the marker of the intermediate frequency, and the primary circuit is tuned so as to obtain symmetry of the positive and negative humps of the curve.

Tuning the ratio detector. The circuit of a ratio detector is shown in Fig. 114. If the secondary circuit is tuned precisely to the intermediate frequency set on the SSG dial, then in case the detector circuit is fully balanced ($C_4=C_5$; $R_1=R_2$, etc.), the output voltage of the detector will be equal to zero. If in this case the primary tuned circuit is off tune, the humps of the frequency response curve will be unequal.

Tuning of a ratio detector with the aid of a frequency response meter does not differ from the tuning of a discriminator. When tuning with the aid of an SSG and a d.c. voltmeter, the unmodulated voltage of the SSG is applied to the grid of the last IF amplifier stage. The d.c. voltmeter

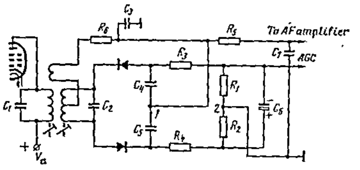

Fig. 114. Circuit of ratio detector

is connected to one of resistors R_1 or R_2 or parallel to capacitor C_6. Now both tuned circuits of the ratio detector are tuned to maximum reading of the voltmeter. After this the voltmeter is connected between points *1* and *2* and the secondary circuit is tuned to zero reading of the voltmeter.

9.5. GENERAL CHECKING OF RECEIVERS

Testing circuits. Radio receiving circuits possess high sensitivity and, therefore, the electromagnetic fields set up by radio stations and various sources of interference can greatly affect the results of testing a receiver.

According to the USSR Standards the level of external interference on all bands should be not less than 25 decibels below the half-normal sensitivity.

For this requirement to be met, receivers are tested in screened rooms in all cases when the conditions of testing require a low voltage to be applied to the receiver input.

When the audio frequency sections of a receiver are tested, the instruments are connected to the receiver pick-up jacks by means of a screened cable, with the screen earthed.

Broadcast receivers employ both external and built-in antennas. During tests, external antennas are disconnected and replaced by dummy antennas. The circuit of a standard dummy antenna for a broadcast receiver is shown in Fig. 115 (the dummy antenna is marked off by a dashed line).

Resistor $R'_A = 80 - R_i$ ohms, where R_i is the internal resistance of the SSG. $L_A = 20$ μH, $C'_A = 125$ pF, $C''_A = 400$ pF, $R''_A = 320$ ohms.

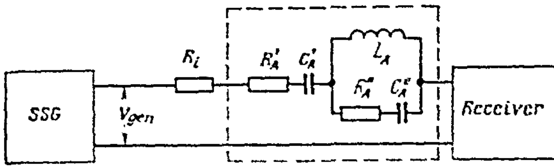

Fig. 115. Circuit for testing broadcast receiver

There also exist several other standard circuits which are connected during tests between the SSG and the receiver input. These coupling circuits designed for various antenna-connecting conditions are made so that the internal resistance of the coupling circuit, measured from the side of the receiver, is equal to the resistance of the disconnected antenna. Let us consider a few examples:

1. A metre-wave receiver has a non-symmetrical antenna matched to a non-symmetrical cable which connects it to the receiver input. In this case it is advisable to use the circuit shown in Fig. 116, selecting $R_1 = \rho - R_i$, where

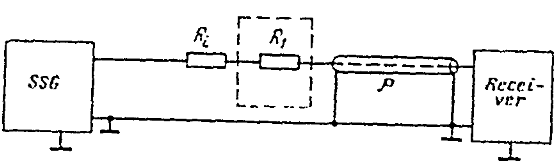

Fig. 116. Connection of generator to metre-wave receiver with unbalanced input

R_i is the internal resistance of the generator, and ρ, the wave impedance of the cable.

2. A metre-wave receiver has a symmetrical antenna connected to the receiver input with a symmetrical cable. In tests use is made of an SSG with an unbalanced output. In

this case the coupling circuit shown in Fig. 117 is used. With correct selection of resistors R_1, R_2, and R_3, the receiver input will remain symmetrical (balanced); the SSG is loaded by a resistance equal to the wave impedance of its output cable; the symmetrical cable is loaded by its wave impedance.

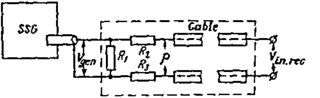

Fig. 117. Connection of generator to metre-wave receiver with balanced input

For a common case, when the wave impedance of the SSG cable is 75 ohms and the wave impedance of the symmetrical cable is 300 ohms, the resistors of the coupling circuit should have the following values: $R_1=87$ ohms, $R_2=110$ ohms, and $R_3=150$ ohms.

If a generator with a balanced output is used, then on condition that the output resistance of the generator is equal to the input resistance of the disconnected antenna, the coupling circuit can be omitted and the balanced cable of the SSG connected directly to the receiver input.

There are also some specific features in reading the output voltage of the SSG. Two cases of calibration of the SSG output voltage exist.

Sometimes the calibration is made on the supposition that the load resistance will be much higher than the output resistance of the SSG. In this case on connection of a matched load the output voltage of the SSG is practically halved. If the output voltage of the SSG is calibrated so that the load resistance is matched to the output resistance of the SSG, the calibration will remain true on connection of coupling matching circuits.

In some generators the output cable is loaded by a matching resistor. For the SSG calibration to remain true, it is

necessary to disconnect this resistor, when loading the SSG with a coupling matching circuit.

When testing for the simultaneous effect of a useful signal and interference, two SSG's are used, one of which simulates the useful signal and the other, the interference signal (Fig. 118).

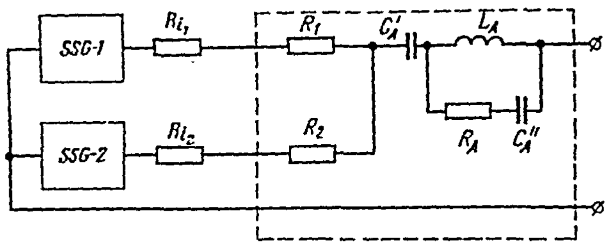

Fig. 118. Connection of two SSG's to amplitude modulation receiver

According to the USSR Standards the following circuit parameters for testing amplitude modulation receivers are provided:

$$C'_A = 125 \text{ pF};\ L_A = 20\,\mu\text{H}$$

$$R_A = 320 \text{ ohms};\ C''_A = 400 \text{ pF}$$

Series resistors R_1 and R_2 can be determined from the following equalities:

when the receiver input is supplied with signal and interference voltages of the same amplitude $R_{i1}+R_1=R_{i2}+R_2=160$ ohms;

when the receiver input is supplied with interference voltage from SSG-I, exceeding several times the voltage of the useful signal from SSG-II, $R_{i1}+R_1=89$ ohms; $R_{i2}+R_2=800$ ohms.

In the first case the input signals are determined by multiplying the SSG output voltages by the factor 0.5. In the second case the input voltage of the interference signal is determined by multiplying the output voltage of SSG-I by the factor 0.9 and the input voltage of the use-

ful signal, by multiplying the output voltage of SSG-II by the factor 0.1.

For measurements in the USW range, if it is necessary to apply two signals from FM SSG's with unbalanced outputs, use is made of the circuit shown in Fig. 119. Resistors R_1, R_2, and R_3 are equal to 25 ohms, while the internal resistance of each of the frequency modulation generators is equal to 75 ohms.

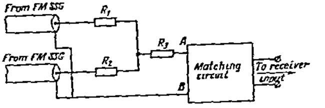

Fig. 119. Connection of two SSG's to frequency modulation receiver

On condition that the FM SSG is calibrated with a matched load, i.e., 75 ohms, connected, the voltage at the input of the matching circuit is equal to the reading of the SSG divided by 2.

When testing receivers with loop or built-in antennas, a standard loop antenna is connected to the SSG output. The field intensity at a distance of 1 metre from the loop in the direction of maximum radiation expressed in μV/m is equal to the product of the reading of the main voltage divider of the AM SSG multiplied by the reading of the decade divider (a voltage of 1 volt is set at the input of the dividers or attenuators). Knowing the field intensity and the effective height of the receiving antenna, it is possible to determine the e.m.f. induced in the receiving antenna.

After assembling the testing hookup, measurement of the receiver parameters is begun.

Checking the bands and calibration accuracy of the receiver dial. The receiver input is supplied with voltage from an SSG (Fig. 120*a*) or a heterodyne wavemeter (Fig. 120*b*). The receiver dial is set to one of the extreme fre-

quencies of each band, and the SSG or heterodyne wavemeter is tuned to maximum reading of the voltmeter connected to the receiver output.

For checking broadcast and other receivers which do not incorporate a beat frequency oscillator the heterodyne wavemeter must have internal amplitude modulation. Instead of a heterodyne wavemeter use can be made of an SSG with sufficiently precise frequency calibration.

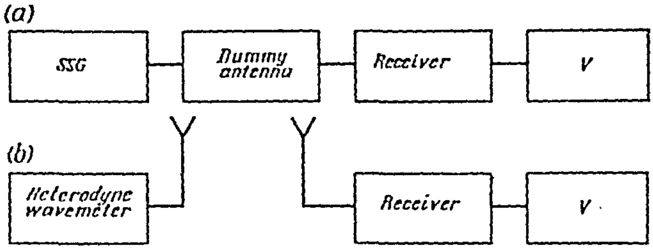

Fig. 120. Checking bands and calibration accuracy of receiver dial

(a) hookup for checking with the aid of SSG; (b) hookup for checking with the aid of heterodyne wavemeter

The calibration error of the receiver dial is checked at three points of the band: two removed by 10-20 per cent from the beginning and end of the band and also at a frequency in the middle. The procedure for measuring frequencies remains the same as that used in checking bands. The reading of the frequency scale of the SSG or the heterodyne wavemeter is compared with the reading of the dial of the tuned receiver.

The *absolute calibration error*

$$\Delta f = f_{rec} - f_s$$

where f_{rec} = frequency set on the receiver dial

f_s = frequency of the signal applied to the receiver input

The *relative calibration error*

$$\gamma = \frac{\Delta f}{f_s} 100\%$$

Measuring the real sensitivity of amplitude modulation receivers. The measurement hookup is shown in Fig. 120*a*. The receiver is tuned to the frequency of the SSG modulated by a frequency of 400 or 1,000 hertzes at a modulation depth of 30 per cent. The tone and bandwidth controls should be in the positions corresponding to maximum gain. The output voltage of the SSG is adjusted so as to obtain a voltage at the receiver output corresponding to a power output of 50 milliwatts.

After this the modulation of the SSG is switched off. Now the voltmeter connected across the receiver output will indicate the noise voltage. If the ratio of the signal voltage corresponding to a power of 50 milliwatts to the noise voltage is less than the specified, the gain of the receiver should be reduced with the volume control and the above measurements repeated. The receiver input voltage V_A at which a power output of 50 milliwatts is obtained at the specified signal-to-noise ratio represents the real sensitivity of the receiver

$$V_A = V_{SSG} \cdot K_{DA}$$

where V_A = real sensitivity

K_{DA} = transfer factor of the dummy antenna

Measuring the real sensitivity of frequency modulation receivers. The measuring procedure remains, on the whole, the same as when measuring the real sensitivity of amplitude modulation receivers. If necessary, a matching circuit, for example, that shown in Fig. 115, is connected between the frequency-modulated generator and the receiver. The same level of power output of 50 milliwatts is used. The modulation frequency is 1,000 hertzes and the frequency deviation, ± 15 kilohertzes. The volume control must also be in the position at which the ratio of the signal and noise voltages at the receiver output is not less than the specified.

Measuring the selectivity and passband. The measuring hookup for amplitude modulation receivers is shown in Fig. 120*a*. The receiver input is supplied from the AM SSG with the specified voltage and the receiver is tuned to the SSG frequency. The volume control is set so as to obtain a

standard receiver output voltage corresponding to a power output of 50 milliwatts.

For determining the selectivity, i.e., the attenuation of a signal of one or another frequency, the tuning of the receiver should remain unchanged, while the frequency of the SSG should be varied by the specified amount Δf and the output voltage of the SSG increased until the standard receiver power output is obtained.

The selectivity

$$S = 20 \log \frac{V''_{SSG}}{V'_{SSG}}$$

where V'_{SSG} = SSG output voltage when tuned to the receiver frequency

V''_{SSG} = SSG output voltage at the given de-tuning

Selectivity is measured on given frequencies and at given positions of the tone and bandwidth controls.

The selectivity of amplitude modulation broadcast receivers is determined as a rule by its adjacent-channel rejection at a de-tuning of ± 10 kilohertzes and by its image frequency rejection at a de-tuning of double the intermediate frequency in the direction of higher frequencies.

Having set the SSG dial to such a frequency, it is necessary to adjust the SSG to the image frequency channel according to the maximum reading of the voltmeter at the receiver output.

Attenuation of an intermediate frequency signal is determined on the receiver frequencies closest of all to the intermediate frequency (408 and 520 kilohertzes). After tuning the receiver to one of these frequencies, the intermediate frequency of 465 kilohertzes should be set on the SSG dial and the SSG tuned to the maximum reading of the voltmeter. At the same time the SSG output voltage should be adjusted so that the standard output of 50 milliwatts is obtained at the receiver output.

The passband is determined in the following way. First, the receiver is tuned to the SSG frequency and the standard power obtained at the receiver output, just as when determining selectivity. Then the SSG is de-tuned to determine frequencies f_1 and f_2 at which, in order to obtain the stan-

dard receiver power output of 50 milliwatts, it is necessary to double the SSG output voltage, as compared to that when the SSG was on tune. The passband

$$\Delta f = f_2 - f_1$$

Measurement of the selectivity and the passband of frequency modulation receivers has the following distinctive features. A d.c. voltmeter is connected to the load of the frequency detector. When a receiver containing a ratio detector is tuned to the FM SSG frequency, the voltmeter gives the maximum reading, and if the receiver contains a discriminator, the voltmeter gives the minimum reading.

First the receiver is tuned in the usual way with frequency deviation of the input signal and an input signal voltage equal to the sensitivity. Then the modulation is switched off and the SSG brought on tune according to the reading of the d.c. voltmeter. Without changing the receiver tuning, the SSG is de-tuned and its output voltage increased until the same reading of the d.c. voltmeter is obtained as in the case of the on-tune condition. The ratio of the FM SSG voltages at de-tuning and on tune characterizes the selectivity of the frequency modulation receiver. By setting the appropriate de-tuning, it is possible to determine the adjacent channel, image channel selectivity, etc. In other respects determination of the selectivity and passband of frequency modulation receivers is done in the same way as with amplitude modulation receivers.

Frequency response of the whole amplification channel (fidelity curve). The fidelity curve shows how the output voltage of the receiver depends on the modulation frequency. The measurement hookup is shown in Fig. 121.

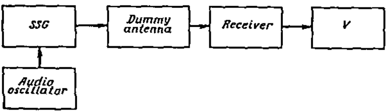

Fig. 121. Hookup for measuring frequency response of whole amplification channel (fidelity curve)

The SSG operates in the external modulation mode. Modulation voltage is supplied from an audio oscillator. The depth of modulation is maintained at 30 per cent when testing amplitude modulation receivers. When testing frequency modulation receivers, the deviation is set at ±15 kilohertzes.

Having set the given carrier frequency on the SSG dial and the given SSG output voltage, tune the receiver to the SSG frequency.

With the aid of the volume control a power output is set equal to one-fourth of the rated receiver output, but not less than 50 milliwatts. Then the modulation frequency is varied to determine how the output voltage depends on the modulation frequency.

Nonuniformity of the frequency response is expressed as the ratio of the maximum or minimum voltage to the voltage at a modulation frequency of 1,000 hertzes. Sometimes nonuniformity of the frequency response is expressed as the ratio of the maximum to the minimum voltage within a given band of modulation frequencies.

Testing AGC systems and volume and tone controls. The AGC system ensures a relatively small variation in the receiver output voltage with variation of the input voltage within wide limits. For checking the AGC system, a given carrier voltage modulated by an audio frequency of 400 or 1,000 hertzes is set at the SSG output. The modulation depth for amplitude modulation receivers is 30 per cent and the deviation for frequency modulation receivers is ±15 kilohertzes.

With the volume control a receiver power output equal to 0.25 of the rated is set. After this the SSG output voltage is decreased a given number of times. The ratio of the voltages at the receiver output at maximum and minimum input voltages characterizes the action of the AGC. The results of the measurements make it possible to determine how many times less the voltage at the receiver output changes in comparison to the change in voltage at the receiver input.

To check the operation of the manual volume control, the audio frequency input of the receiver is supplied with such a voltage from the audio oscillator which produces

the standard receiver power output of 50 milliwatts with the volume control in the following positions:

corresponding to the maximum gain (let us designate the output voltage of the audio oscillator corresponding to the power output of 50 milliwatts as V'_{AO});

corresponding to the minimum gain as V''_{AO}.

The ratio of the voltages $\frac{V'_{AO}}{V''_{AO}}$ characterizes the action of the manual volume control; it should be within specified limits.

The action of the tone control is checked on specified frequencies: in the region of lower frequencies on 100 hertzes and in the region of higher frequencies on 5,000, 8,000, 10,000, or 12,000 hertzes. For checking the action of the tone control, the pickup jacks (AF input of the receiver) are supplied with a specified voltage, frequency of 1,000 hertzes, and by means of the manual volume control a definite receiver output voltage is set. After this the position of the manual volume control should not be changed. Having set one of the check frequencies and the specified voltage of the audio oscillator, the voltage at the receiver output should be measured with the tone control in the extreme positions. The increase and decrease of the receiver output voltage at the extreme positions of the tone control in comparison to the voltage on the medium frequency of 1,000 hertzes characterizes the action of the tone control.

Review Questions

1. Describe the functions and the main parameters of radio receivers.
2. What is the procedure for checking a radio receiver operability?
3. What is the procedure for aligning intermediate frequency filters? How is spurious tuning to be avoided?
4. What is the procedure for tuning radio frequency circuits? How is spurious tuning to be avoided?
5. What are the distinctive features of tuning frequency modulation receivers?
6. How are the main parameters of a receiver measured? What coupling circuits are used in testing circuits?
7. How can the frequency response of the whole amplification channel be measured? How can the action of the AGC system and the volume and tone controls be checked?

CHAPTER X

Adjusting and Testing Television Receivers

10.1. GENERAL DATA. FREQUENCY CHARACTERISTICS

Television transmitters radiate picture and sound signals. Within each television broadcasting channel, the transmitter radiates two carrier frequencies: the picture carrier and the sound carrier.

The picture carrier is amplitude-modulated by picture signals that have the form of pulses; the amplitude of them is proportional to the illumination of the picture element, and the duration, to the size of the element in the horizontal direction. Darker picture elements are represented by pulses of greater amplitude, and wider elements, by pulses of greater duration.

The picture carrier is also amplitude-modulated by synchronizing or sync pulses. The amplitude of these pulses is greater than that of the very highest picture signals. If it is considered that the highest picture signals correspond to the black level, i.e., to the unilluminated elements of the picture, the amplitude of the sync pulses corresponds to the blacker-than-black level.

The sound carrier is frequency-modulated by the sound accompaniment signals. Fig. 122 shows a spectrum of picture and sound signals of one television channel. As seen from the characteristic, the full frequency spectrum of a single channel occupies a frequency band of 8 megahertzes.

A frequency band of ± 250 kilohertzes is occupied by the sound channel, the rest of the spectrum, by the picture channel. The picture and sound carriers are spaced 6.5 megahertzes apart.

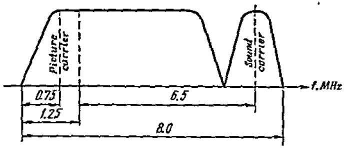

Fig. 122. Frequency response of television channel

Modern television receivers contain a common channel where both the picture and sound signals are converted and amplified. The block diagram of a television receiver is shown in Fig. 123.

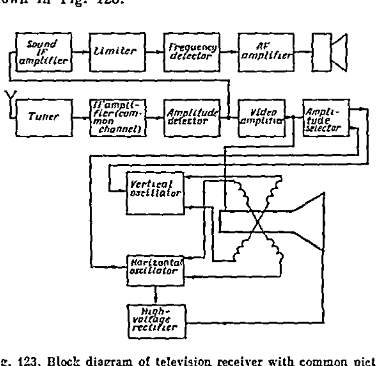

Fig. 123. Block diagram of television receiver with common picture and sound channel

The tuner is a standardized unit which contains a radio frequency amplifier, a converter, and a local oscillator. On switching from one television channel to another, a switch manipulates the appropriate input, RF amplifier, and local oscillator tuned circuits. The frequency response of the RF amplifier is shown in Fig. 124. The RF amplifier provides amplification of the full television signal of the given channel and diminishes the effect of interference from adjacent channels. At the output of the tuner mixer, picture and sound intermediate frequencies develop which are modulated by picture and sound signals, respectively.

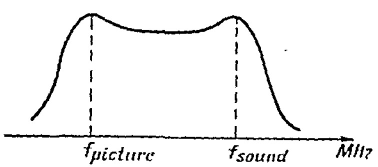

Fig. 124. Frequency response of radio frequency amplifier

The local oscillator frequency is higher than the picture and sound carrier frequencies. The intermediate frequencies are equal to the difference between the local oscillator frequency and those of the picture and sound carriers, and, consequently, after conversion the frequency spectrum becomes reversed: the picture intermediate carrier becomes higher than the sound intermediate carrier, with the higher frequencies of the full television signal corresponding to the lower intermediate frequencies.

The converted television signal is amplified in the picture IF amplifier channel, the frequency response of which is shown in Fig. 125. From this curve it can be seen that the picture intermediate carrier is equal to 34.25 megahertzes, and the sound intermediate carrier, to 27.75 megahertzes. For the sound signals not to distort the picture, the gain of the IF amplifier on the sound accompaniment frequencies should comprise 1-3 per cent of the gain on middle frequencies. The gain on the picture carrier should be equal to about 50 per cent of the gain on middle frequencies, that is due to the fact that within a frequency band of ± 1 megahertz adjoining the picture carrier the transmitter radiates doubled power.

If the gain on the picture intermediate frequency were

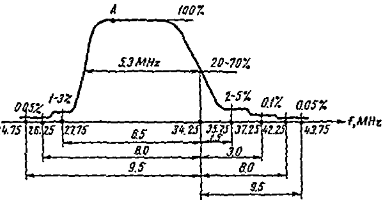

Fig. 125. Frequency response of picture IF amplifier channel

to exceed 50 per cent of the gain on medium frequencies, the lower modulation frequencies would be emphasized, and the definition of the image would become low, i.e., the borders between the black and white elements of the picture would be blurred. If the gain on the picture intermediate carrier were to be considerably below the 50 per cent level, there would be a relative boosting of higher frequencies of the picture signal, the definition would improve, but the quality of the picture would deteriorate due to the effect of phase distortion: the picture would stand out in unnaturally bold relief, sharper borders between elements possessing different shades would appear.

The video signals are developed by an amplitude detector. There are various amplitude detector circuits which can produce either a positive or a negative video signal. A video signal is considered to be positive, if crossing from the black level to the white level corresponds to positive increments in the instantaneous values of signal voltage or current. In the case of negative polarity, on the contrary, crossing from the black level to the white level corresponds to negative increments in the instantaneous values of signal current or voltage. If the video signal is applied to the control electrode of a picture tube, it must have a positive polarity, and if it is applied to the cathode, a negative polarity. Otherwise, a negative picture will appear

on the screen. The voltage developed at the output of the amplitude detector is insufficient for modulating the electron beam from black to white, depending on the brightness of the picture elements transmitted by the television transmitter. Therefore, the video signals are amplified by one or two video amplifier stages.

A correctly assembled video amplifier requires no adjustment. If the shape of its frequency response and its amplification factor need to be checked, the procedure described in Sec. 6.1 is used. In this case the output of the frequency response meter is connected to the input of the video amplifier, and the input of the FRM, to the cathode of the picture tube. The typical frequency response of a video amplifier is shown in Fig. 126.

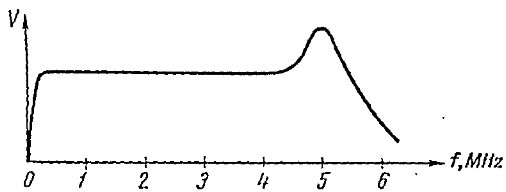

Fig. 126. Frequency response of video amplifier

Let us now consider the sound channel.

Since the amplification of the sound signals in the common channel is not high, the need of amplifying these signals additionally arises. For this purpose use is made of the circumstance that at the output of the video detector, in addition to the picture video pulses and the sync pulses, there also develops the difference frequency between the picture and sound carriers, i.e., a frequency of 6.5 megahertzes modulated by the sound accompaniment signals.

Voltage of this frequency is applied to the sound IF amplifier, the frequency response of which is shown in Fig. 127*a*. The passband of the sound IF amplifier is equal to 300 kilohertzes.

The frequency-modulated sound accompaniment signal is fed from the output of the sound IF amplifier to the limiter and frequency detector which develops the sound accom-

paniment signals. These signals are amplified by the AF amplifier and fed to the speaker.

The amplitude response of the detector is shown in Fig. 127c. The zero point of the response curve should be dead on the point 6.5 megahertzes. The amplitude response of the sound channel is most nonlinear (Fig. 127b), that is

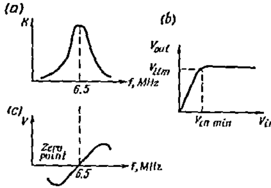

Fig. 127. Characteristics of sound accompaniment channel

(a) frequency response of IF amplifier; (b) amplitude response of sound accompaniment channel; (c) amplitude response of detector

due to the action of the limiter. Amplitude limitation eliminates parasitic amplitude modulation by the picture signals.

Obtaining the required frequency responses of the picture and sound channels is one of the most important and time-consuming tasks of an adjuster of television receivers. The adjustment procedure does not differ from that described in Chapter VI.

As a frequency response meter use can be made of a special device for adjusting television receivers. It includes a wobbulator with all the necessary bands for observing the frequency response of the tuner on any of the television channels. In addition, it has a sweep frequency range necessary for observing the frequency response of the common picture and sound channel. The latest models of devices for adjusting television receivers are also provided wit

a sweep frequency range with a centre frequency of 6.5 megahertzes for tuning sound channels.

The input of the oscilloscopic indicator of the device for adjusting television receivers includes a detector head for developing the envelope of the output voltage of that section of the television receiver which is under test.

Like the frequency response meter, the televisor adjusting device (TAD) has provision for producing frequency scale markers which make it possible to determine the positions of the picture and sound carriers, the passband, the width of the flat section for the sound accompaniment signal on the frequency response curve of the common channel IF amplifier, etc. On the basis of the frequency response curves, it is not difficult to determine the relative amplification on the various frequencies.

Having connected the output of the TAD to the input of the receiver circuit under test, and to the output of this circuit, the input of the device and having obtained a frequency response curve on the screen of the cathode ray tube of the device, it is necessary to adjust the tuned circuits so as to obtain a response curve of the required shape. In this way it is possible to tune the RF amplifier, the common IF amplifier, the sound IF amplifier, and the frequency detector and to obtain the required overall frequency responses of the sound and picture channels.

10.2. PARAMETERS CHARACTERIZING PICTURE QUALITY

The quality of the picture is characterized by a number of parameters: brightness, focussing, definition, contrast, stability of synchronization, and linearity of horizontal and vertical scanning.

Picture *brightness* is determined with the greatest precision with the aid of a photometer, but under factory testing conditions, adjustment and checking of brightness is usually done visually: brightness should be adjustable within wide limits.

By *contrast* is meant the relationship between the brightness of the brightest parts of the picture and the brightness of the darkest parts.

In adjusting contrast the gain of the picture channel is varied; this simultaneously varies the sweep of the video signal applied to the picture tube. Adjustment of contrast and brightness are interrelated. When brightness is adjusted, the d.c. voltage at the picture tube modulator varies. If in this case the modulator potential proves too high, the video pulses corresponding to black picture elements will not cut off the picture tube, and the black elements will appear grey, while the grey elements will appear white. With the position of the brightness control unchanged and excessive increase in the contrast, the video signal corresponding to the grey elements in the original picture will prove sufficient for cutting off the picture tube, and the grey elements will appear black on the screen. Only by joint adjustment of brightness and contrast is it possible to achieve that an image on the screen be sufficiently bright and at the same time sufficiently contrast.

The electron beam should be well focussed, i.e., it should trace a sufficiently thin line. With poor focussing neighbouring lines will partially overlap and the picture quality will deteriorate.

By *definition* is meant the ability of a television receiver to reproduce fine details of a picture without distortion. One of the causes of poor definition can be poor focussing. True, if the focussing is poor and the lines partially overlap, fine details of the picture, which occupy one or several lines vertically, will prove greatly distorted or may be lost altogether, i.e., be indiscernible.

Another cause of worsened definition can be poor frequency response of the picture channel. If the frequency response sags in the region of higher frequencies, the leading and trailing edges of the video pulses are drawn out. This reduces the extent of short-duration pulses which correspond to fine details of the picture; the borders between these details become blurred, and the picture loses definition.

The synchronization system ensures the stability of the image, since it synchronizes the scanning of the picture tube beam, both horizontally and vertically, with the beam of the camera tube at the television centre. To obtain synchronization, the full television signal radiated by the transmitter contains horizontal and vertical sync pulses.

The ratio of the sides of the raster should be 3:4. Otherwise the images of objects will be drawn out either horizontally or vertically, circles will turn into ovals, faces will be either drawn out or compressed, etc.

Whether the natural proportions of images are retained also depends on the linearity of horizontal and vertical scanning. Tracing a line of the image, the picture tube beam must move across the screen at a constant speed. Otherwise identical objects will have different sizes in the horizontal direction. Similar nonlinear distortion develops in the vertical direction if vertical scanning is not linear.

All television receivers are divided into three classes. Receivers of the first class possess the highest quality picture and sound. They necessarily incorporate a number of automatic controls: automatic gain control, automatic brightness control, automatic stabilization of picture size, etc. In receivers of the third class these controls are not obligatory; a certain reduction is allowed in definition and in the sensitivity of the sound and picture channels. Their power consumption is considerably less and does not exceed 150 watts. TV receivers of the second class occupy a half-way position between those of the first and third classes.

10.3. ADJUSTING PICTURE CHANNEL

The picture channel consists of the following main parts: a tuner, an IF amplifier, a video detector, and a video amplifier. The tuner, the IF amplifier, and the video detector simultaneously serve as elements of the sound channel, while in some models of television receivers, the common channel also includes the video amplifier or one of its stages.

Adjusting the tuner. The circuit diagram of a tuner unit is shown in Fig. 128. This is a standardized unit and at the present time is used in most serially produced valve television receivers. It consists of a radio frequency amplifier employing valve *V1*, a mixer employing the pentode section of valve *V2*, and a local oscillator employing the triode section of valve *V2* in a Colpitts circuit.

The tuner is designed for reception of television broad-

casts on any of twelve television channels. Switching from channel to channel is obtained by interchanging the coils of the input circuit L_1 and L_2, of the RF amplifier anode circuit L_4 and L_5, and of the local oscillator tuned circuit L_6.

Figure 128 shows the coils of only one television channel. All the coils are arranged around the circumference of a tur-

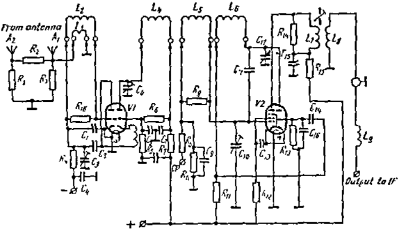

Fig. 128. Circuit diagram of tuner

ret which is turned by the switch. Coaxial with the shaft of the turret switch is the shaft of variable capacitor C_{12} intended for adjusting the tuning of the local oscillator. Resistor R_1 serves for matching the input of the television receiver to the wave impedance of the 75-ohm cable. Resistors R_2 and R_3 form a voltage divider for attenuating the signals of nearby television transmitters.

The RF amplifier employs a cascode circuit. The left half of valve *V1* operates in an RF amplifier circuit with an earthed cathode; this ensures a relatively high input resistance of the stage, and consequently, the possibility of using step-up transformer $L_1 - L_2$ in the input circuit. The step-up transformer amplifies the voltage arriving from the antenna. The right-hand triode of valve *V1* is included in the anode load circuit of the left-hand triode

of the valve. It operates as an amplifier with an earthed grid (in respect of radio frequencies its grid is earthed via capacitor C_5). Such a stage reduces the coupling between the anode circuit of the RF amplifier and the input circuits, that is necessary to prevent self-excitation.

To reduce feedback via the grid-anode capacitance of the left-hand triode, neutralization is introduced with the aid of trimming capacitor C_3 included in a bridge neutralization circuit. This capacitor can be adjusted so that variation of the voltage at the left triode does not vary the voltage at its grid.

The anode circuit of the RF amplifier is tuned with the aid of trimming capacitor C_6.

The main advantage of the cascode circuit is its low internal noise level, as compared to an amplifier employing a pentode, and that it possesses approximately the same gain as the latter.

The operating principle of the mixer and local oscillator requires no explanation, since similar circuits are employed in radio receivers which were dealt with in detail previously.

Alignment of the tuner amounts to obtaining the frequency response shown in Fig. 129*a* and setting the local oscillator frequency.

The local oscillator frequency is set with the aid of a heterodyne wavemeter which is loosely coupled to the local oscillator of the television receiver.

For the picture intermediate carrier to be equal to 34.25 megahertzes, the frequency of the local oscillator should be higher than the picture carrier of the television transmitter by 34.25 megahertzes. For this variable capacitor C_{12} is set in a middle position and the local oscillator is tuned to the indicated frequency by means of the slug of coil L_8. Variable capacitor C_{12} is used during operation of the television receiver, therefore its shaft is brought outside the cabinet.

For aligning the radio frequency circuits use is made of an attachment which has the same input resistance as the picture channel IF amplifier. In this way the attachment functions as a dummy load for the tuner unit. The hookup for adjusting a tuner is shown in Fig. 129*b*.

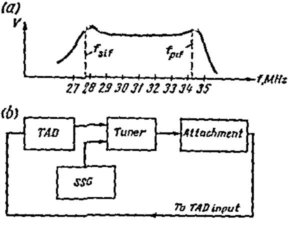

Fig. 129. Alignment of tuner

(a) frequency response; (b) adjustment hookup

For aligning the anode circuit of the mixer, the output of the televisor adjusting device (TAD) is connected to the grid circuit of the mixer (check point *CP*), and its input, to the output of the attachment.

The frequency switch of the TAD is set in such a position that the frequency-modulated generator covers a frequency band of 25-36 megahertzes. Coils L_7 and L_8 are tuned to obtain the frequency response shown in Fig. 129*a*. The left hump of the mixer frequency response should coincide with the marker for 27.75 megahertzes and the right one, with the marker for 34.25 megahertzes.

The positions of the humps can be determined with greater accuracy with the aid of an SSG connected to check point *CP* and generating unmodulated RF voltage. In those brief intervals of time when the frequency of the frequency-modulated generator is close to that of the SSG, pips will appear on the frequency response curve. If the frequency of the SSG is varied, the position of the pip will vary accordingly. Thus, it is possible to calibrate, in frequency, any point of the frequency response curve, including the humps.

To align the RF amplifier, the output of the TAD is switched to the left triode of valve *V1* and its input, to check point *CP*. With its switch the television receiver is set to one or another television channel, and with the switch of the TAD the appropriate frequency deviation of the wobbulator is set.

The required frequency response of the RF amplifier is obtained by adjusting capacitors C_6 and C_{10} and also by shifting the outer turns of coils L_4 and L_5. The frequency response curve of the RF amplifier was shown in Fig. 124.

For aligning the input circuits, the output of the TAD is connected to the input of the tuner and the input of the TAD, to check point *CP*; the frequency response is adjusted by shifting the outer turns of coils L_1 and L_2.

For checking the overall frequency response of a tuner, similar to that shown in Fig. 129*a*, the output of the TAD is connected to the input of the tuner, and its input, to the output of the attachment. Frequency response is checked on all twelve channels.

Aligning the IF amplifier of the common picture and sound channel. From the tuner output the signal is applied to the input of the IF amplifier of the common picture and sound channel. An IF amplifier circuit employing valves *V1*, *V2*, and *V3* is shown in Fig. 130, and the frequency response of an IF amplifier is shown in Fig. 125. The required shape of the frequency response curve is obtained by aligning the tuned circuits to definite frequencies which are usually indicated in the circuit diagram (in Fig. 125 they are expressed in MHz).

For this the input of the TAD is connected to the load of detector D_1 and its output cable, to the control grid of a controlled stage. Alignment is begun with the last stage of the IF amplifier. An aligned stage is shunted by a resistor, thus flattening its frequency response. On completing stage-by-stage alignment, the shunting resistors are disconnected, the frequency response of the whole IF amplifier is observed and, if necessary, additional adjustment is carried out.

Adjustment is usually made of rejector circuits L_3C_4 and L_6C_{12}. These circuits are intended for attenuation of the sound accompaniment frequency of 27.75 megahertzes

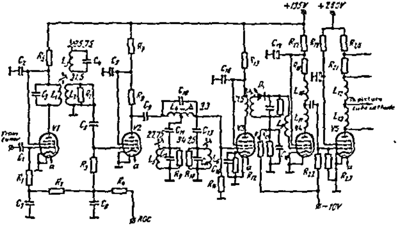

Fig. 130. Circuit diagram of IF amplifier of common picture and sound channel

and for obtaining a steep fall-off of the IF amplifier frequency response beyond the limits of the passband (due to the rejector circuit being tuned to frequency of 35.75 megahertzes).

In stage-by-stage alignment these circuits are tuned to minimum voltage on the above-mentioned frequencies. When aligning the IF amplifier as a whole, rejector circuit L_5C_{12} is tuned to obtain a small flat section in the region of the sound intermediate frequency carrier of 27.75 megahertzes, and rejector circuit L_3C_4 is tuned to obtain the required fall-off of the frequency response in the region of the picture intermediate carrier. It should not be forgotten that the picture intermediate carrier should be located at about the middle of this slope.

Under serial production conditions, stage-by-stage alignment of the IF amplifier is not usually done, instead the required shape of the frequency response of the whole amplifier is obtained. In this case the output of the TAD is connected to the input of the IF amplifier, and its input, to the load of video detector D_1.

Knowing the effect of each tuned circuit of the IF amplifier on the shape of various sections of the frequency

response curve, the adjuster quickly achieves a response of the right shape and the correct positioning of the picture and sound intermediate frequency carriers.

Checking the video amplifier. The video amplifier employs valves *V4* and *V5* (see Fig. 130). As was mentioned before, it requires no adjustment despite the inclusion of complex frequency correction circuits. For checking the operation of the video amplifier, audio frequency voltage of a definite amplitude is applied to its input. In this case dark and light bands should appear on the screen of the picture tube.

10.4. ADJUSTING SOUND CHANNEL

The sound carrier modulated by the sound accompaniment signals is fed from the antenna of the television receiver to the input of the tuner unit and then passes through the common IF amplifier channel which is simultaneously the picture channel IF amplifier (see Fig. 123).

In the previous section it was pointed out that the sound intermediate carrier is specially suppressed by the rejector circuits so as to avoid intense interference with the reception of picture signals.

At the output of the common channel the sound signals possess an insufficient amplitude and to amplify them use is made of a sound IF amplifier tuned to the frequency of 6.5 megahertzes. One of the circuits of the final part of the sound accompaniment channel is shown in Fig. 131. The sound IF amplifier employs valve *V1*. Valve *V2* functions as a limiter, and diodes D_1 and D_2 as a frequency detector. The detected signal is applied to the audio frequency amplifier employing valves *V3* and *V4*. The first stage of the AF amplifier is a voltage amplifier, and the second, a power amplifier. The power amplifier is loaded by two speakers Sp_1 and Sp_2.

The AF amplifier is checked by ear and, if necessary, adjusted and checked according to the procedure described in Sec. 6.2.

After checking the AF amplifier, adjustment of the IF amplifier, the frequency detector, and the limiter is undertaken (see Sec. 9.4.). The operating conditions of the li-

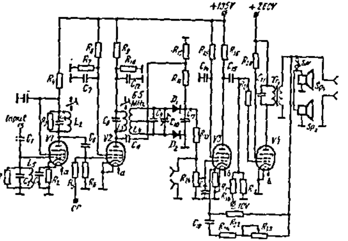

Fig. 131. Circuit of final part of sound channel

miter should be selected so that parasitic amplitude modulation by the picture signals or by interference will not affect the quality of the sound accompaniment.

The sound IF amplifier is aligned with the aid of a TAD or an SSG and a valve voltmeter. The sound IF amplifier must be aligned before tuning the frequency detector and limiter, since the level of the output signal of the frequency response meter is insufficient for tuning the frequency detector. If the sound IF amplifier is aligned, the output of the TAD or any frequency response meter is applied to the input of the sound IF amplifier. Then the frequency-modulated signal is preamplified by the sound IF amplifier and its amplitude becomes sufficient for normal tuning of the frequency detector.

Otherwise the adjustment of the final part of the sound channel of television receivers does not differ from the adjustment of frequency modulation radio broadcast receivers.

10.5. ADJUSTING SYNCHRONIZATION AND SCANNING SYSTEM

The electron beam traces the picture on the screen of the picture tube, varying its brightness under the action

response curve, the adjuster quickly achieves a response of the right shape and the correct positioning of the picture and sound intermediate frequency carriers.

Checking the video amplifier. The video amplifier employs valves *V4* and *V5* (see Fig. 130). As was mentioned before, it requires no adjustment despite the inclusion of complex frequency correction circuits. For checking the operation of the video amplifier, audio frequency voltage of a definite amplitude is applied to its input. In this case dark and light bands should appear on the screen of the picture tube.

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In the previous section it was pointed out that the sound intermediate carrier is specially suppressed by the rejector circuits so as to avoid intense interference with the reception of picture signals.

At the output of the common channel the sound signals possess an insufficient amplitude and to amplify them use is made of a sound IF amplifier tuned to the frequency of 6.5 megahertzes. One of the circuits of the final part of the sound accompaniment channel is shown in Fig. 131. The sound IF amplifier employs valve *V1*. Valve *V2* functions as a limiter, and diodes D_1 and D_2 as a frequency detector. The detected signal is applied to the audio frequency amplifier employing valves *V3* and *V4*. The first stage of the AF amplifier is a voltage amplifier, and the second, a power amplifier. The power amplifier is loaded by two speakers Sp_1 and Sp_2.

The AF amplifier is checked by ear and, if necessary, adjusted and checked according to the procedure described in Sec. 6.2.

After checking the AF amplifier, adjustment of the IF amplifier, the frequency detector, and the limiter is undertaken (see Sec. 9.4.). The operating conditions of the li-

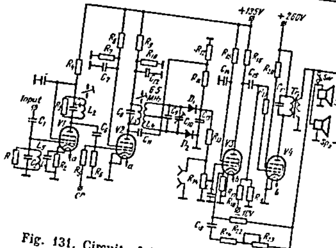

Fig. 131. Circuit of final part of sound channel

miter should be selected so that parasitic amplitude modulation by the picture signals or by interference will not affect the quality of the sound accompaniment.

The sound IF amplifier is aligned with the aid of a TAD or an SSG and a valve voltmeter. The sound IF amplifier must be aligned before tuning the frequency detector and limiter, since the level of the output signal of the frequency response meter is insufficient for tuning the frequency detector. If the sound IF amplifier is aligned, the output of the TAD or any frequency response meter is applied to the input of the sound IF amplifier. Then the frequency-modulated signal is preamplified by the sound IF amplifier and its amplitude becomes sufficient for normal tuning of the frequency detector.

Otherwise the adjustment of the final part of the sound channel of television receivers does not differ from the adjustment of frequency modulation radio broadcast receivers.

. ADJUSTING SYNCHRONIZATION AND SCANNING SYSTEM

The electron beam traces the picture on the screen of picture tube, varying its brightness under the action

of the picture signals. The whole picture is made up of 625 lines. The beam is made to travel along the lines under the action of the sawtooth current of the horizontal scanning generator. This current flows through the deflection coils of the picture tube causing the electron beam to deflect in the horizontal direction proportionally to the instantaneous value of the horizontal scanning current.

Shifting of the beam vertically from line to line is caused by the sawtooth current of the vertical scanning generator. In one second 25 frames are transmitted, but the vertical scanning generator has a frequency of 50 hertzes. This means that in one-fiftieth of a second one field is transmitted tracing the picture every other line, i.e., 312.5 lines in all. This is known as *interlaced scanning*. During the time of the second field, the other 312.5 lines are traced. Thus, one field reproduces the odd lines and the other field, the even lines.

The process by which interlaced scanning is obtained is explained in Fig. 132. For the sake of simplicity we shall

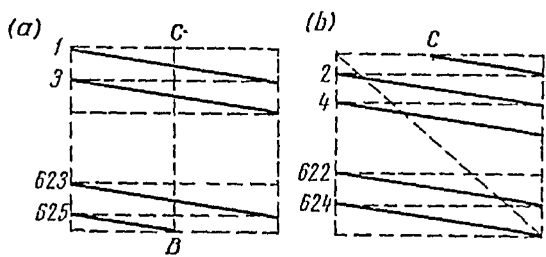

Fig. 132. Formation of interlaced scanning (dotted lines show the flyback)

suppose that the flyback of the beam in both horizontal and vertical scanning occurs instantaneously. Crossing over from the field of odd lines to the field of even lines occurs along line *BC*, with the point of transition located in the middle of the forward travel of the horizontal scanning. If the odd field is superimposed on the even, a full raster containing 625 lines is obtained.

Actually the flyback of the beam in horizontal and vertical scanning does not occur instantaneously, and for the

flyback not to leave a trace on the picture, the picture tube is cut off for this time by horizontal and vertical blanking pulses, the amplitude of which corresponds to the black level. The horizontal flyback should begin and end within the time of the blanking pulse. This is achieved with the aid of sync pulses, the duration of which is somewhat less than the duration of the blanking pulses (Fig. 133). The

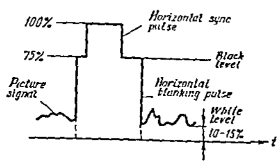

Fig. 133. Video signal

leading edge of the sync pulse interrupts the forward travel of the beam horizontally, and the horizontal generator crosses over to the flyback mode. At the end of the blanking pulse forward travel along the line begins again. Synchronization of the vertical scanning generator is achieved in a similar way.

Figure 134 shows the circuit of the amplitude selector and the vertical scanning system of the "Rekord-4" television receiver. The blanking and sync pulses along with the picture signals are fed from the anode load of the video amplifier to the cathode of the picture tube and to the grid of the amplitude selector employing valve *V1*.

The operating principle of the amplitude selector is explained in Fig. 135. The video signal, the voltage of which at the output of the video amplifier is 40-50 volts, only partially falls within the working region of the anode-grid characteristic of the selector valve (Fig. 135*a*). As the sync pulses comprise 25 per cent of the full swing of the television signal, at a voltage of 40-50 volts the share of the syn-

pulses is 10-12 volts. It is necessary that the anode-grid characteristic in the region of negative values of V_g should not exceed 5-7 volts. This ensures reliable singling out of the sync pulses even with fluctuations in the voltage of the video signal. To narrow the spread of the anode-grid characteristic the anode and the screen grid of the selector are supplied with reduced voltage.

In the circuit shown in Fig. 134, reduced voltage is supplied to the screen grid from voltage divider R_4R_5. In the

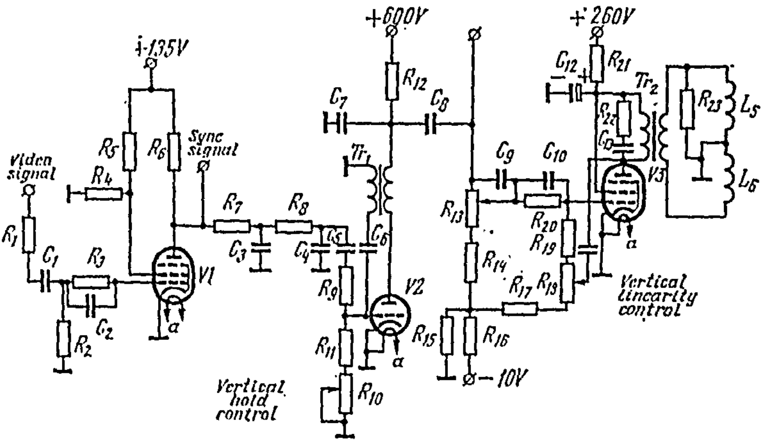

Fig. 134. Circuit of amplitude selector and vertical scanning

process of adjusting the synchronization channel, it is necessary to check the anode and screen-grid voltages. With excessive screen-grid voltage, the spread of the anode-grid characteristic may prove too broad (Fig. 135*b*), and, in addition to the sync pulses, blanking pulses and part of the video signal may appear at the output of the selector. This may lead to violation of synchronization. It is convenient to check whether the selector is operating correctly with the aid of an oscillograph.

Vertical sync pulses are supplied from the anode of valve *V1* to integrating circuit $R_7C_3R_8C_4$ (see Fig. 134). This

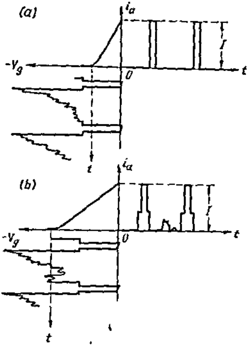

Fig. 135. Operating principle of amplitude selector
(a) correctly selected operating conditions; (b) incorrectly selected operating conditions

circuit suppresses the shorter horizontal sync pulses and singles out the longer field sync pulses which control the operation of the vertical scanning generator.

The vertical scanning generator employs valves *V2* and *V3*. The self-excited blocking oscillator employs valve *V2*, and its frequency can be adjusted with the aid of potentiometer R_{10}. With correct selection of this frequency the blocking oscillator is reliably synchronized by the field sync pulses. The vertical scanning output stage employs valve *V3* and has a transformer output. The secondary circuit of the output transformer includes vertical deflection coils L_5 and L_6. The picture size is adjusted vertically with the aid of potentiometer R_{13}, and the linearity of the vertical scanning, with potentiometer R_{18}.

The sync signal from the anode of valve *V1* is fed to differentiating circuit C_1R_1 (Fig. 136) which singles out the horizontal sync pulses and does not pass the vertical sync pulses.

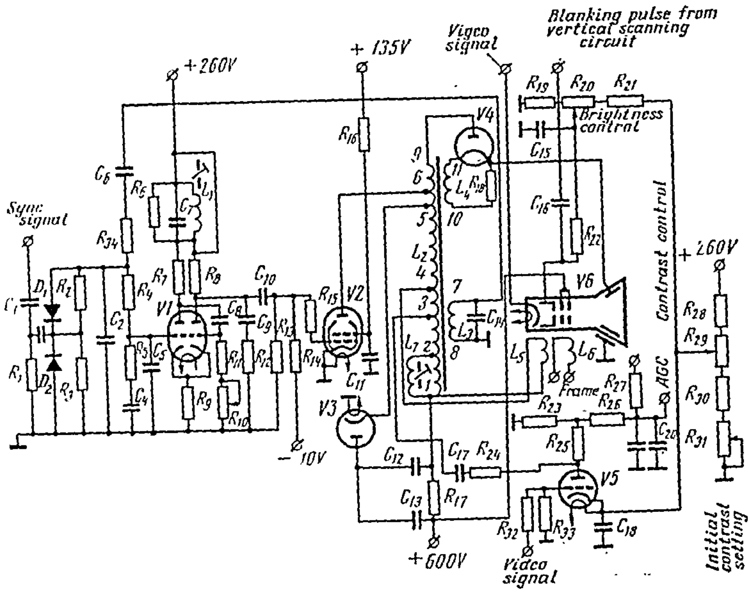

Fig. 136. Horizontal scanning circuit

The horizontal scanning circuit consists of a phase dis criminator employing diodes D_1 and D_2, a multivibrato employing valve *V1*, the output stage employing valve *V2* a damper employing valve *V3*, and a high-voltage rectifie employing valve *V4*. The multivibrator operates in the sel oscillatory mode and produces the horizontal scanning pu ses.

The phase discriminator serves for automatic contr of the horizontal scanning frequency. It reacts instant neously to departure of the multivibrator frequency fro the recurrence frequency of the horizontal sync pulses.

Detectors D_1 and D_2 not only develop the sync pu voltage across resistor R_1 but also that of the horizon

scanning pulses which arrive from winding *7-8* of the horizontal transformer via capacitor C_8 and resistor R_{31}. When the sync-pulse and horizontal-scanning frequencies coincide, the phase discriminator does not affect the operation of the multivibrator.

At the phase discriminator output, i.e., at the grid of the multivibrator valve, a positive or negative voltage appears, if the multivibrator frequency departs from that of the sync pulses. This voltage at the phase discriminator output varies the multivibrator frequency so as to restore full coincidence of the horizontal-scanning and horizontal sync-pulse frequencies.

The horizontal deflection coils are connected to the output stage with the aid of autotransformer Tr_1 which performs a number of functions:

matching of the load with the output valve;

production of high voltage for supplying the picture tube.

Winding *6-9* (see Fig. 136) supplies the high-voltage rectifier employing valve *V4*.

At the start of the horizontal flyback, i.e., at the moment when valve *V2* is cut off, a high e.m.f. develops across the high-voltage winding, which is rectified by valve *V4*.

The damping circuit is also connected with the aid of the autotransformer. The circuit including damping diode *V3*, capacitor C_{12}, and part of the winding of the horizontal output transformer dampens the parasitic oscillations at the beginning of the forward trace, improves linearity, increases the swing of the sawtooth current in the horizontal deflection coils, and makes the circuit more economic.

Diode *V3* is connected to winding *1-5* of the horizontal output transformer in such a way that at the moment the horizontal flyback terminates, the potential of its cathode becomes significantly lower than the potential at its anode, and the diode begins to conduct. In this case capacitor C_{12} charges via the diode and the transformer winding, and simultaneously current builds up linearly in the deflection coils, ensuring the beginning of the horizontal forward trace. As capacitor C_{12} charges, the charging current begins to fall off, but by that time valve *V2* opens and its anode

is detected by the grid-cathode section of the valve. Rectified current proportional to the signal level flows through resistors R_1, R_2, and R_4 across which a voltage develops that is used for automatically varying the grid voltage of the controlled valves. Filter R_5, C_1, R_7, and C_2 serves for smoothening the pulsation of the rectified voltage. Manual gain control is obtained with the aid of potentiometer R_2, the contrast control.

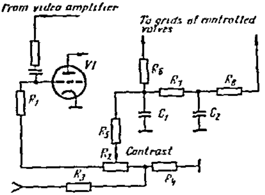

Fig. 137. AGC circuit with amplitude selector

A key AGC circuit is shown in Fig. 136. Its main element is the amplifier employing valve $V5$, which conducts only when it is simultaneously supplied: with control pulses of the horizontal output transformer on the anode and with the sync pulses on the grid. At all other moments valve $V5$ is cut off by the positive voltage applied to its cathode from potentiometer R_{29}.

The pulses that develop at its output are proportional to the amplitude of the sync pulses and. consequently, to the level of the received signal. These pulses are rectified by filter R_{28}, C_{19}, C_{20} and are applied in negative polarity to the grids of the controlled valves.

10.6. ELECTRICAL TESTING

Preparation for testing. Comprehensive testing of a television receiver can be carried out only in a specially equipped laboratory. In serial production conditions wide use

made of television testers which supply the individual work places with a special test pattern (the 0249) and sound accompaniment signals. In addition, for electrical testing of television receivers use is made of amplitude-modulated standard signal generators VHF AM SSG, as well as VHF FM SSG, frequency response meters, audio oscillators, oscillographs, d.c. and a.c. voltmeters, and other equipment.

The input of the television receiver must be matched to the generator output. Usually a generator is used which has a coaxial output cable with a wave impedance of 75 ohms. The generator is connected to the receiver input via a voltage divider shown in Fig. 138. The voltage at the receiver input is three times less than the voltage at the SSG output (if the SSG is calibrated with a matched load).

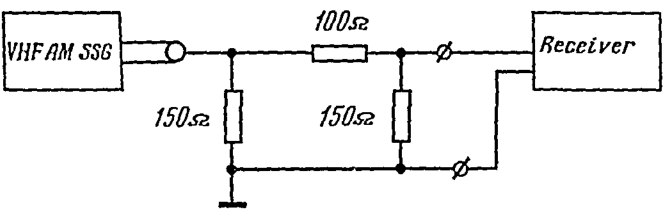

Fig. 138. Matching generator output to receiver input

For measuring some parameters the receiver input is supplied from two generators, i.e., AM SSG and FM SSG. The hookup for connecting the receiver to the generators is shown in Fig. 119. The voltage at the input of the matching circuit from either of the generators is half the voltage at the SSG output, calibrated in voltage across the load.

The picture carrier frequency is set on the VHF AM SSG and the sound carrier frequency, on the VHF FM SSG. The accuracy with which the carrier frequencies $f_{car.p}$ and $f_{car.s}$ are set is checked with the aid of a heterodyne wavemeter.

In most tests a standard picture carrier amplitude of 1 millivolt is set, and a sound carrier amplitude of 0.5 millivolt.

If a definition corrector is included in the receiver, it is set in such a position at which the picture carrier voltage

at the picture tube cathode is half the voltage in the middle part of the frequency response curve. For this:

1. Connect a valve voltmeter to the modulator of the picture tube.

2. At the middle position of the contrast control, measure the voltage in the AGC line and apply to it the same voltage from an external source as shown in Fig. 139.

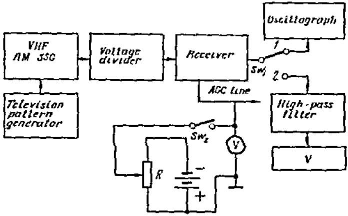

Fig. 139. Hookup for testing picture channel

3. Set the frequency of the VHF AM SSG to 2 megahertzes, i.e., set the frequency $f_{car.p}+2$ MHz and measure the voltage at the picture tube cathode.

4. Set the picture carrier frequency on the VHF AM SSG, and with the definition corrector make the voltage at the picture tube cathode half the voltage at the frequency $f_{car.p}+2$ MHz.

Checking the picture channel. The illumination characteristics of a television receiver are determined by the brightness and the contrast. Brightness is measured with a photometer in a darkened room. The accepted unit of brightness is the brightness of a surface one metre square, which develops in a direction at right angles to that surface a luminous intensity equal to one candle power. This unit known as nit (nt). The normal brightness of a televis screen in a darkened room is equal to 20 nits, and in

made of television testers which supply the individual work places with a special test pattern (the 0249) and sound accompaniment signals. In addition, for electrical testing of television receivers use is made of amplitude-modulated standard signal generators VHF AM SSG, as well as VHF FM SSG, frequency response meters, audio oscillators, oscillographs, d.c. and a.c. voltmeters, and other equipment.

The input of the television receiver must be matched to the generator output. Usually a generator is used which has a coaxial output cable with a wave impedance of 75 ohms. The generator is connected to the receiver input via a voltage divider shown in Fig. 138. The voltage at the receiver input is three times less than the voltage at the SSG output (if the SSG is calibrated with a matched load).

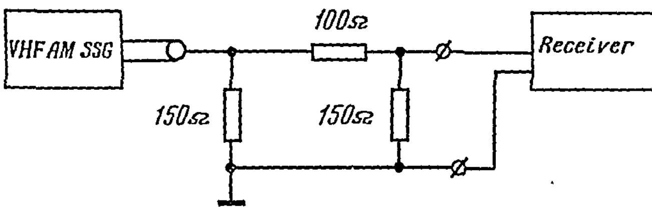

Fig. 138. Matching generator output to receiver input

at the picture tube cathode is half the voltage in the middle part of the frequency response curve. For this:

1. Connect a valve voltmeter to the modulator of the picture tube.

2. At the middle position of the contrast control, measure the voltage in the AGC line and apply to it the same voltage from an external source as shown in Fig. 139.

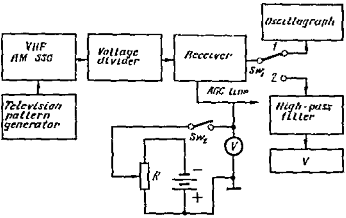

Fig. 139. Hookup for testing picture channel

3. Set the frequency of the VHF AM SSG to 2 megahertzes, i.e., set the frequency $f_{car.p}+2$ MHz and measure the voltage at the picture tube cathode.

4. Set the picture carrier frequency on the VHF AM SSG, and with the definition corrector make the voltage at the picture tube cathode half the voltage at the frequency $f_{car.p}+2$ MHz.

Checking the picture channel. The illumination characteristics of a television receiver are determined by the brightness and the contrast. Brightness is measured with a photometer in a darkened room. The accepted unit of brightness is the brightness of a surface one metre square, which *develops in a direction at right angles to that surface a luminous intensity equal to one candle power. This unit is known as nit (nt). The normal brightness of a television screen in a darkened room is equal to* 20 nits, and in a

weakly illuminated room, to 40 nits. Contrast is characterized by the relationship of the brightest elements of the image to the darkest elements.

The sensitivity of the picture channel, limited by amplification, is determined as the minimum voltage at the receiver input at the rated voltage at the output of the picture channel, i.e., at the cathode of the picture tube. For measuring this parameter, the receiver input is supplied with a picture carrier voltage modulated by a checkerboard pattern or a sinusoidal voltage. That receiver input voltage at which the rated output voltage is obtained (on condition that the contrast control is in the maximum gain position) is called the sensitivity limited by amplification.

The sensitivity limited by noise is that minimum receiver input voltage at which the output voltage (at the picture tube cathode) is ten times greater than the noise voltage. For measuring sensitivity limited by noise, use is made of the hookup in Fig. 139.

First, all the operations are done as when measuring sensitivity limited by amplification. With a d.c. voltmeter the voltage in the AGC line is measured and then the same voltage is applied from an extraneous source. The rated voltage is set at the picture tube cathode. Then the modulation of the VHF AM SSG is switched off and with potentiometer R the former voltage is set in the AGC line. With a thermistor voltmeter, the noise voltage is measured at the picture tube cathode. If this voltage is ten or more times less than the rated, then the sensitivity limited by noise will be equal to the sensitivity limited by amplification. Otherwise it is necessary to increase the bias with potentiometer R and the voltage at the SSG output so that the rated voltage is again obtained at the picture tube modulator. Then the modulation of the SSG is switched off again and the noise voltage is measured. On the basis of the obtained data a curve is plotted of the rated voltage at the picture tube cathode to the noise voltage vs the voltage at the receiver input (Fig. 140). That voltage at the receiver input at which the noise voltage is ten times less than the rated voltage at the picture tube cathode will be equal to the sensitivity limited by noise.

Fidelity characteristic of the picture channel. The relationship of the voltage at the picture tube cathode versus the frequency of the modulation voltage is known as the *fidelity characteristic* of the picture channel. To plot a fidelity curve the receiver input is supplied with the voltage of the picture carrier modulated by a pulse with a sinusoidal filling at a frequency of 100 kilohertzes at a modulation depth of 30 per cent, and the receiver is tuned. The voltage

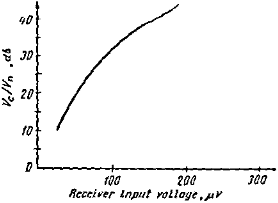

Fig. 140. Measurement of picture channel sensitivity

at the picture tube modulator is measured with an oscillograph or a valve voltmeter.

Having tuned the receiver, such a voltage is set at the generator output which produces the rated voltage at the picture tube cathode. Maintaining the SSG output voltage constant, the modulation frequency is varied from 100 kilohertzes to 6.5 megahertzes. The amplitude of the output voltage, i.e., the voltage at the picture tube cathode, versus the modulation frequency is plotted as a curve, like that shown in Fig. 141. This is the fidelity curve of the picture channel.

Selectivity of a television receiver is characterized by the ratio of gain on the interference frequency to the gain on the picture carrier frequency. This is determined on the following interference frequencies:

1. The sound carrier frequency of the adjacent channel occupying the region of lower frequencies.

2. The sound carrier frequency of the given channel, which, as was indicated above, is higher than the picture carrier by 6.5 megahertzes.

3. The picture carrier frequencies of neighbouring channels.

4. The frequencies of image channels.

When measuring selectivity, the level of the picture channel output voltage is maintained constant. The receiver

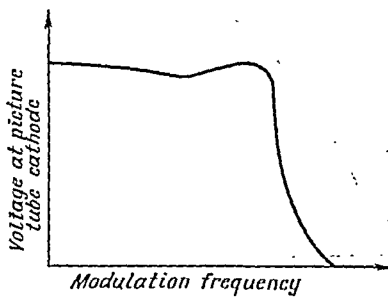

Fig. 141. Picture channel fidelity curve

input is supplied with modulated voltage of the picture carrier from a VHF AM SSG, the receiver is tuned, and the rated voltage is set at its output. The AGC valve is disconnected from the controlled valves, and voltage from an extraneous source is applied to the AGC line. After this the voltage at the output of the picture channel is decreased by 12 decibels (3.9 times) by decreasing the output voltage of the VHF AM SSG. Maintaining this voltage (at the cathode of the picture tube) constant, the frequency of the VHF AM SSG is varied and the dependence of the voltage at the receiver input on the frequency is measured. The measurement results determine the selectivity

$$\sigma = 20 \log \frac{V_2}{V_1}$$

where V_1=voltage at the receiver input on the picture frequency carrier

V_2 = voltage at the receiver input on one of the interference frequencies

In all measurements a modulation factor of 50 per cent is maintained at a modulation frequency of 1,000 hertzes.

Testing the sound channel. The sound channel is actually a frequency modulation receiver. The checking procedure has been dealt with in Sec. 9.5. To take into account the effect of the picture signals on the operation of the sound channel, a hookup for testing is assembled using two generators at the input: an AM SSG and an FM SSG (Fig. 142).

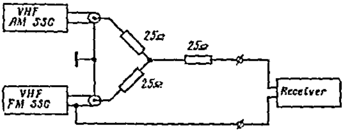

Fig. 142. Connection of AM SSG and FM SSG for testing sound channel

The sensitivity of the sound accompaniment channel limited by amplification is determined by the voltage at the receiver input at which the rated voltage is obtained across the voice coil of the speaker at maximum gain. For measuring this parameter the receiver input is supplied with the sound carrier voltage of the channel being tested; the voltage is modulated by a frequency of 1,000 hertzes with a deviation of ±50 kilohertzes. Simultaneously the receiver input is supplied with a video signal from a VHF AM SSG, modulated by a frequency of 100 kilohertzes. In all measurements a ratio of 2:1 of the picture carrier voltage to the sound carrier voltage is maintained at the receiver input.

The volume control is set in the maximum volume position, and the tone control, in the widest passband position. With the contrast control the rated voltage is maintained at the picture tube cathode.

Gradually the voltages at the output of the VHF FM SSG and the VHF AM SSG are increased until the rated voltage is obtained at the output of the sound channel (across the speaker voice coil). The voltage obtained in this case at the receiver input is equal to the sensitivity limited by amplification.

The sensitivity of the sound channel limited by interference is determined by the minimum input voltage at which the rated voltage is obtained at the output of the channel, while the level of interference from the picture signals, the scanning circuits, and the supply sources does not exceed the specified limits.

Having carried out all the operations in the same way as when determining sensitivity limited by amplification, the modulation of the sound carrier should be removed and the interference voltage measured across the voice coil of the speaker. If this voltage proves to be greater than the specified, then it is necessary to increase the voltage at the output of the VHF FM SSG (and correspondingly of the VHF AM SSG to maintain the ratio of 2:1) and with the volume and contrast controls to set the rated voltage across the voice coil and at the picture tube cathode. After this the modulation is switched off again and the interference voltage is re-measured.

The receiver input voltage produced by the VHF FM SSG, at which the rated receiver output voltage is obtained and the interference voltage across the voice coil does not exceed the permissible, is equal to the sensitivity of the sound channel limited by interference.

Checking of the other parameters of the sound channel as a whole and of its elements does not differ from the checking of frequency modulation broadcast receivers.

10.7. CHECKING TELEVISION RECEIVER BY THE 0249 TEST PATTERN

The 0249 test pattern shown in Fig. 143 is regularly broadcast from the Soviet television centres. The same test pattern is supplied to the work places of adjusters from a television tester. Along with the test pattern, sound accompaniment is transmitted, making it possible to check

the picture channel and the sound channel in simultaneous operation. This helps bring to light the effect exerted by one channel on the other.

How well the sound channel operates can be judged by the volume level, the tone quality, and the absence of distortion. With sufficient experience an adjuster can detect abnormal operation of the sound channel by ear. The sound

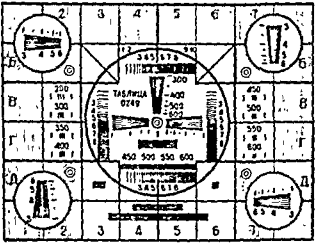

Fig. 143 Type 0249 test pattern

quality can deteriorate due to the effect of interference; the most important of them is the interference caused by the vertical blanking and sync pulses and by the vertical scanning. This interference creates a typical vertical scanning frequency hum. Low frequency hum can be due to poor filtration of the supply circuits and unsatisfactory wiring of the heater circuits.

The 0249 test pattern provides a means for rapidly evaluating the quality of the image, the synchronization, and the scanning systems. It also allows a judgement to be made of the quality of focussing, contrast, brightness, definition, picture size and linearity, synchronization stability, the quality of the interlaced scanning, the presence of frequency and phase distortion.

Focussing. The quality of focussing depends primarily on the shape of the electron beam in the plane of the screen. The smaller the diameter of the spot and the better its shape, the better the focussing. For checking the shape of the electron beam use is made of the small concentric circumferences located in the centre of the pattern and in squares Б-2, Д-2, Б-7, Д-7. If the cross section of the beam has the shape of a circle, then the thickness of the lines forming the concentric circumferences will be the same in all directions. The quality of focussing is checked with the aid of the horizontal wedges located in the centre and in the corners of the pattern. By turning the focussing knob, the best differentiation of the separate lines of the wedges should be obtained. Under the horizontal wedges in the centre of the pattern there are vertical lines corresponding to the figures 300, 400, 500, and 600, while at the wedges in the corner of the pattern these figures are replaced by the numbers 3, 4, 5, and 6. On having obtained optimal focussing at normal brightness and contrast, it is necessary to note the place where the separate lines of the edges flow together and at that place to read the corresponding figure showing how many lines are discernible on the screen. The obtained results should conform to the specifications of the television receiver.

Brightness and contrast. As was mentioned above, brightness and contrast are adjusted together. At normal contrast the brightness control should allow the brightness to be varied smoothly from complete blacking out of the screen to the appearance of flickering and defocussing of bright spots of the image. The glowing of the screen should change uniformly over the whole surface. The contrast control should allow the contrast to be varied from a barely visible image on the screen to an excessively black one.

The quality of adjustment of the brightness and contrast is checked by two horizontal and two vertical bands located in the central part of the screen. These bands have ten gradations of brightness which are marked on the pattern by the figures 3, 4, 5, 6, 7, 8. Having achieved optimal contrast at normal brightness, it is necessary to note where the brightness gradations become indistinguishable and to read the figure opposite this place showing how many gra-

dations of brightness are distinguishable on the screen. This figure should conform to the specifications of the given television receiver.

Scanning linearity. If linearity is violated, various parts of the picture appear in different proportions, i.e., the natural proportions of the sizes of the picture elements are violated. For checking linearity it is first necessary to adjust *correctly the size of the picture so that* the ratio of the raster width to its height conforms to the standard 4:3 or 4:5 (for tubes with a deflection angle of 110°). In case of violation of linearity, the squares making up the test pattern are compressed in some places and drawn out in others. The shape of the circle in the centre and at the corners of the pattern is also distorted. If these circles are drawn out vertically, *vertical linearity has been violated; if they are* drawn out horizontally, there is a horizontal violation of linearity.

Definition. By definition is meant the resolution of the television receiver, i.e., its ability to reproduce small picture details on the screen. It is customary to differentiate between horizontal and vertical definition. Vertical definition depends on the width of the line which, in its turn, depends on the quality of the focussing. This makes it possible to check the horizontal definition, just as the quality of focussing, by the horizontal wedges in the centre and the corners of the 0249 test pattern. *According to the Soviet* standard, the picture is made up of 625 lines and with ideal definition about 600 lines are discernible vertically (approximately 25 lines are used up by the vertical flyback) while the lines of the horizontal wedges do not flow together even in the narrowest part of the wedge. In practice, in television receivers of the second class, at optimal focussing, 500-600 *lines are discernible in the horizontal* wedges *located in* the centre of the screen and 350-400 lines, in the horizontal wedges located at the corners of the pattern.

Horizontal definition shows the maximum number of black and white lines of the same thickness that can be reproduced along a line. It depends on the frequency and phase response of the picture channel and also on the diameter of the scanning beam of the picture tube. For quantitative evaluation of horizontal definition, the 0249 test pattern

has vertical wedges in the centre and the corners of the pattern, a scale of group definition located in the lower part of the bigger circle under the figures 450, 500, 550, and 600, and the groups of lines in squares В-2, Г-2, В-7, and Г-7.

Definition is determined after tuning the local oscillator of the receiver and obtaining optimal brightness, contrast, and focussing. Horizontal definition is read from the figures located next to the vertical wedges (300, 400, 500, 600 near the vertical wedge in the centre and 3, 4, 5, 6 near the vertical wedges in the corners of the pattern). The reading should be made at that place where the vertical lines of the wedge flow together and become indiscernible. For receivers of the second class the horizontal definition in the centre of the screen is 450-500 and at the edges not less than 400. It is somewhat less than the vertical definition, this being due to the presence of frequency and phase distortion in the picture channel. The groups of vertical lines in the squares mentioned above are spaced at various distances apart. Horizontal definition corresponds to the number above that group of lines in which the separate lines and also the spaces between them are still discernible.

Synchronization. Synchronization should ensure stability of the picture under the effect of various factors which vary the natural frequencies of the horizontal and vertical scanning generators. To check synchronization stability it is necessary to perform the following operations:

1. Turn the vertical hold knob in both directions from the position of stable reception. In this case the picture should shift up and down and be brought easily to a standstill.

2. The horizontal hold knob should turn in both directions by about 90° without violation of horizontal synchronization. When synchronization is violated, black bands appear on the screen instead of the picture.

Stable synchronization should be obtained with the HORIZONTAL HOLD and VERTICAL HOLD knobs in a medium position, i.e., there should be a reserve for turning these knobs from the position corresponding to stable synchronization. When varying the contrast throughout wide limits, synchronization should not be violated.

Interlaced scanning. In case of violation of interlaced scanning, the distance between the lines of the first and the *second fields changes, becoming greater or smaller*, and when the distance is equal to zero, the lines of the two fields blend into one. When the lines of the two fields blend, the number of lines making up the picture is halved. *Violation of normal operation of vertical scanning is indicated* by the *following symptoms:*

1. The blending of the lines of two fields is detected by the noticeable reduction in the number of lines making up the picture.
2. Periodic variation of the distance between the lines of the fields is detected by the appearance of serrated projections on the diagonal lines of squares Б-3 and Б-6.
3. With variation of the distance between the lines of two fields, the ends of the horizontal wedges in the centre of the pattern bend upwards and downwards, forming a fan.

Frequency and phase distortion. The quality of reproduction of the lower *frequencies of the picture signals* is checked with the aid of the black *bands located in the* centre of the pattern and in squares Д-3, Д-6, Е-3, Е-4, Е-5, and Е-6.

With poor passage of *lower frequencies*, white "tails" *form to the right of the dark bands; they decrease the definition* of the border between the light and dark parts of the image creating a blurred impression. With further attenuation of lower frequencies, synchronization stability *deteriorates. Boosting of lower frequencies causes the appearance* of grey "elongations" to the right of the dark bands.

Mutual interference of sound and picture signals. Interference of sound signals with the reception of the picture *manifests itself in the shape of horizontal bands which appear* on the screen in beat with the sound. Interference of picture signals with the reception of sound signals manifests itself in the form of low-pitched rumbling and noise, the level of which *varies when contrast is adjusted.*

Distortion of the raster. The raster on the screen of the *television receiver should be strictly rectangular with sharply* defined borders and uniform glowing over the whole *screen. Some of the distortions of the raster appear as violation* of parallelism of its *opposite sides*, darkening of

the corners of the raster, darkening of one of its sides, curving of vertical lines, etc. The causes of distortion of the raster are usually to be found in faults of the horizontal and vertical output stages and in the deflection system of the picture tube.

Review questons

1. Explain the circuit of a television receiver with a common picture and sound channel.
2. Explain the circuit and the procedure for aligning a tuner unit.
3. Explain the shape of the frequency response curve of an IF amplifier of the common picture and sound channel. What is the procedure for aligning it?
4. Explain the circuit and the procedure for adjusting the synchronization and scanning system of a television receiver.
5. Which are the main parameters characterizing the picture channel? How are they measured?
6. Which are the main parameters characterizing the sound channel? How are they measured?
7. How is the test pattern used for adjusting a television receiver? What are its elements designed for?

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